Air Repair

Pollution From Incinerators Can Be Overcome

(pages 109 and 119)

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The Editor welcomes writers interested in air pollution problems and encourages them to use the pages of this journal for the expression of their opinions. But neither he nor the Association assumes responsibility for the validity of the opinions expressed herein.

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Photochemical Ozone Formation with Hydrocarbons and Automobile Exhaust

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AND
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The most typical characteristic of the Los Angeles smog is its strong oxidizing effect.[1] This effect can be demonstrated by bubbling smog air through buffered potassium iodide solution, which is readily oxidized with liberation of iodine. Dyes such as indigo sulfonic acid and crystal violet are decolorized. On the other hand, leuco compounds such as phenolphthalin, the reduced form of the acid-base indicator, phenolpthalein, are oxidized to colored derivatives.[2]

Using phenolphthalin as a smog indicator during 24 hr. periods, it is evident that the oxidant reaches a peak concentration during the daytime. In Pasadena, during the summer months, the oxidant concentration rises in the morning to a maximum between one and three o'clock in the afternoon, and is practically absent during the night. Determinations carried out over several months have shown that the maximum in oxidant agrees well with subjective impression of the smog intensity as judged by eye irritation and odor. The oxidizing reaction is due, not to one substance, but is the resultant of the action of ozone, peroxides and nitrogen oxides, counteracted by the presence of sulfur dioxide.[3][4]

Nitrogen dioxide originates in all high temperature combustions which take place in fuel burning industrial plants and in the explosion of air-gasoline mixtures in automobile engines. Its concentration does not exceed 0.4 ppm. in heavy smog, and is therefore far below its toxic level of 20 ppm.[5] The presence of NO_2, however, has an accelerating effect on the main process leading to smog formation: *the oxidation of organic material under the influence of sunlight.*

During this photochemical oxidation process ozone is formed and concentrations of 0.5 ppm. (V/V) are found in the Los Angeles area, which exceed by a factor of 20 the ozone concentrations found in uninhabited areas. Using the characteristic cracking of rubber as a test method it has been shown that the ozone concentration rises sharply during a smog period. The formation of ozone can be duplicated in the laboratory by exposing hydrocarbon vapors and nitrogen oxides to sunlight at concentrations of the reactants which have been found in the Los Angeles air during smog attacks.[6][7] Ozone formation during photochemical oxidation is not limited to hydrocarbons but is also shown by their oxidation products—acids, aldehydes, ketones and alcohols. From a practical point of view, it is important that the irradiation of gasoline in the presence of NO_2 also leads to the formation of ozone and causes severe rubber cracking, and the Los Angeles County Air Pollution Control District has demonstrated the ozone forming property of the air near sources of hydrocarbon release.

Experimental Procedure

In duplicating the ozone formation observed in polluted air, it is essential to adhere to a rather narrow concentration range of hydrocarbon and nitrogen dioxide, which was confirmed by a set of experiments in which the hydrocarbon, 3-methylheptane, and the NO_2 concentrations were systematically varied. Artificial light from a bank of 12 Westinghouse 40 w. blue fluorescent light bulbs was used for the irradiation to eliminate the variable intensity of sunlight. The bulbs were arranged in the form of a "U", 4 bulbs to a side, and spaced so that when a 5 *l.* flask was placed in the center, the bulbs were approximately 0.5 in. from the sides and bottom of the flask. An oxygen atmosphere adjusted to 30% humidity, and an irradiation time of 10 hr. were selected as standards in the experimental procedure. The ozone formed was measured by the cracking observed on bent rubber strips of standard size (8x20x2 mm.) suspended in 5 *l.* flasks during irradiation.

To remove volatile impurities the rubber strips were exhaustively extracted with carbon tetrachloride at room temperature, and the last traces of solvent were removed in vacuum. It was found advantageous to use as one measure the sum of the depth of *all* cracks as measured under the microscope (100 x) using an ocular micrometer. The measurement of crack depth was made on a freshly cut surface exposed by making a longitudinal cut through the test strip 1 mm. from the edge.

In the experiments the rubber was bent and the ends tied together with glass thread used to suspend the test strip in the flask. The calibrations against known ozone concentrations were made in flasks of the same size as those used in the irradiation experiments. In the concen-

1. Haagen-Smit, A. J., *Engineering and Science, 14,* 7-13 (1950).
2. Haagen-Smit, A. J., *J. Applied Nutrition, 6,* 298 (1953).
3. *L. A. County Air Pollution Control District Second Technical and Administrative Report* (1950-51).
4. Bradley, C. E., and Haagen-Smit, A. J., *Rubber Chem. and Tech., 24,* 750-5 (1951).
5. Haagen-Smit, A. J., *Ind. Eng. Chem 44,* 1342 (1952).
6. Haagen-Smit, A. J., Bradley, C. E., and Fox, M. M., *Proc. Second National Air Pollution Symposium,* Pasadena, Calif., May 1952.
7. Haagen-Smit, A. J., Bradley, C. E., and Fox, M. M., *Ind. Eng. Chem., 45,* 2086 (1953).

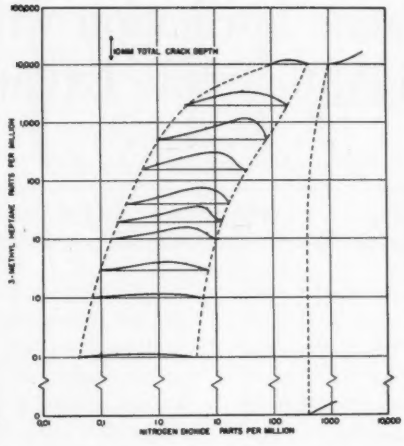


Fig. 2. Rubber Cracking with 3-Methylheptane and NO_2. Logarithmically Plotted. ⟶

Fig. 1. Ozone Formation with 3-Methylheptane and NO_2. Hydrocarbon Concentration Constant; NO_2 Concentration Varied.

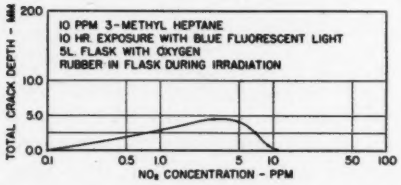
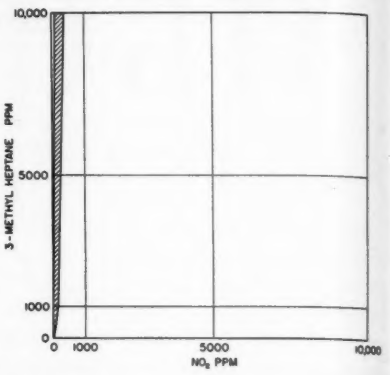

10 PPM 3-METHYL HEPTANE
10 HR EXPOSURE WITH BLUE FLUORESCENT LIGHT
5L. FLASK WITH OXYGEN
RUBBER IN FLASK DURING IRRADIATION
TOTAL CRACK DEPTH - MM
NO₂ CONCENTRATION - PPM

Fig. 3. Area of Ozone Formation with 3-Methylheptane and NO_2. Linear Chart.



tration range used, the total crack depth is proportional to the ozone concentration, 1.0 mm. corresponding to 3 ppm. of ozone.

Fig. 1 shows the result obtained with a constant hydrocarbon concentration of 10 ppm. and NO_2 concentration varying from 0.1 to 100 ppm. A small amount of NO_2 is necessary before cracking of the rubber can be observed. In the presence of 10 ppm. of hydrocarbon, rubber cracking is observed when the NO_2 concentration is greater than 0.1 ppm. After passing through a maximum at 4 ppm., the rubber cracking diminishes until at 10 ppm. of NO_2 no cracks are formed during the 10 hr. irradiation. Similar curves were found for concentrations of 0.1, 1.0, 3.0, 10, 20, 40, 150, 400, 2,000 and 10,000 ppm. of hydrocarbon. These results are compiled in Fig. 2. It is seen that at higher concentrations of hydrocarbon the lowest and highest concentrations of NO_2 at which cracking takes place have both increased. For example, at 400 ppm. of hydrocarbon these concentrations are, respectively, 1.0 and 100 ppm. The area of concentrations of hydrocarbon and NO_2 where rubber cracking takes place in these experiments is indicated in Fig. 2 by dotted lines. At concentrations higher than 400 to 1,000 ppm. of NO_2 the rubber test can no longer be used in irradiation experiments, since NO_2 alone causes rubber cracking in the dark through a direct reaction between the NO_2 and the rubber. This limit is indicated by the dotted line at the right of the ozone forming area. At still higher concentrations of about 10,000 ppm. NO_2, stiffening of the rubber occurs, and finally, at 100,000 ppm. the rubber is completely disintegrated into a viscous mass. Fig. 3, plotted on a linear, rather than a logarithmic scale, shows how narrow the range of effective concentrations for ozone formation really is.

The phenomenon that ozone formation is limited to definite relative proportions of hydrocarbon and NO_2, observed with 3-methylheptane, is apparently equally true for other hydrocarbons and their oxidation products. At a concentration of 3 ppm. and varying concentrations of NO_2, the hydrocarbons n-butane, n-pentane, n-hexane, n-heptane, n-octane, n-nonane, and hexene-1 gave curves similar to the one obtained with 3-methylheptane, with optimum ozone formation at from 1 to 3 ppm. NO_2. It has been observed that as the length of the carbon chain in the straight chain paraffins increases from C_4 to C_9, the ozone forming capacity becomes greater. Methane and ethane were found to be inactive. The effect of branching and of the presence and location of double bonds is now being investigated.

While for experimental reasons artificial light and oxygen were used, it was of interest to see if similar results could be obtained with sunlight and air. Fig. 4 shows the similarity of curves obtained by plotting the crack depth obtained from 3 ppm. of 3-methylheptane and variable concentrations of NO_2 after 10 hr. irradiation in oxygen in artificial light, and after 3 hr. sunlight irradiation in an atmosphere of synthetic air (80% nitrogen and 20% oxygen of 30% humidity). The general shape of the curves obtained in these experiments can be attributed to at least two simultaneous reactions: 1) the formation of ozone, and 2) the removal of ozone by NO_2 and the oxidation products of the hydrocarbon. That NO_2 does react with ozone is well known, and especially at higher concentrations this removal of ozone will play an important role. In our experiments it has been observed that at the upper limits of NO_2 concentrations when no cracking appears after 10 hr., longer irradiation does produce cracking. It is most likely that during this induction period the NO_2 concentration has dropped until it comes within the

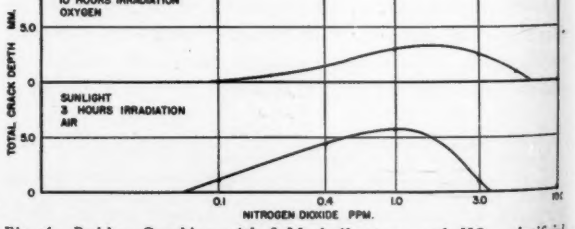


Fig. 4. Rubber Cracking with 3-Methylheptane and NO_2. Artificial Light and Oxygen vs. Sunlight and Air.

range of ozone formation. This shift in the composition of the mixture is also brought about by the reaction of NO_2 with the hydrocarbon and its oxidation products. When ozone formation stops, NO_2 is practically absent.

The rubber strip suspended in the flask during the irradiation continually removes the ozone formed, and is in competition with the products that will react with ozone. Although the reaction with the rubber strip takes from 20 to 30 minutes to remove the ozone nearly quantitatively from a 5 *l.* flask, the rate at which the rubber reacts with the ozone is sufficiently greater than the degradation reaction to be able to show considerable ozone formation. We find that the average rate of ozone formation during the first 10 hr. irradiation of 3 ppm. of 3-methylheptane and 1 ppm. of NO_2 is about 0.8 ppm./hr. After 100 hr. slight cracking is still observed, and at that time the total crack depth corresponds to 20 ppm. of ozone, clearly indicating a chain reaction of considerable extent.

The high values obtained in these experiments are possible only because the rubber strip continuously removes the ozone formed. If, however, the ozone is not removed, it will react with the hydrocarbon and its oxidation products and the nitrogen oxides. Consequently, the ozone measured after a certain length of irradiation time in the absence of rubber will represent the excess of ozone due to the different rates of these reactions. The reaction by which ozone is formed is only slightly faster than those which destroy it. When we attempt to isolate ozone we isolate only the slight excess resulting from the difference in the rate of these reactions. In the analysis of air samples it is this excess of ozone which is measured.

In duplicating these phenomena in the laboratory, hydrocarbons and their oxidation products were irradiated in the presence of NO_2, and the ozone was determined after exposure for different lengths of time. The ozone concentration was measured in two ways: first, by measurement of the rubber cracking (the rubber being introduced *after* the irradiation, and not during the irradiation as previously described) and second, by passing the irradiated mixture through several traps held at —183°C., only ozone passing through, while NO_2, with its higher boiling point (24°C.) is trapped. The ozone passing through the traps was determined by both the phenolphthalin and the potassium iodide methods. Fig. 5 shows the results of such measurements on irradiated mixtures of 3-methylheptane and NO_2, at concentrations of 3 ppm. and 1 ppm., respectively. The experiments were performed with blue fluorescent light in 5 *l.* flasks filled with oxygen at a humidity of 30%.

The ozone present after 4, 5, 10, 20, 24 and 30 hr. was determined. Fig. 5 shows that after 5 hr. a concentration of 1 ppm. of ozone is established which remains nearly constant for about 20 hr. When duplicate flasks were kept in the dark for 1 hr. before measuring the ozone content, the ozone concentration was reduced to one-half the value obtained directly after irradiation. In order to keep the level of ozone concentration at 1 ppm. for 20 hr., approximately 14 ppm. of ozone must have been formed during that time. The experiments previously described, in which the rubber strips were suspended in the flasks during irradiation, indicated the formation of 12 ppm. of ozone during the period between 5 and 25 hr. These experiments confirm the conclusion reached earlier, that a considerably greater amount of ozone is produced than could be expected on the basis of a stoichiometric reaction of 3 ppm. of hydrocarbon and 1 ppm. of NO_2.

These experiments have also been carried out with sunlight and air. With 3-methylheptane at 3 ppm. and NO_2 at 1 ppm., a maximum of 1.6 ppm. of ozone was reached in 3 hr. At 3 ppm. and 0.4 ppm., respectively, a maximum of 1.2 ppm. of ozone was obtained after 5 hr. These concentrations of hydrocarbon and nitrogen oxides correspond closely to values actually found in the analysis of Los Angeles smog.

Ozone Formation from Automobile Exhaust

With the knowledge that ozone formation is limited to a definite area of concentration of hydrocarbon and NO_2, problems of a more practical nature, such as the production of ozone from automobile exhaust, could be undertaken.[8] Once the concentration of hydrocarbon and NO_2 in the exhaust is known, the dilution at which ozone formation could be expected to take place can be read from Fig. 6.

8. Haagen-Smit, A. J., Fox, M. M., Mader, P., and Levy, B., *Report to L. A. County Air Pollution Control District*, July 1954.

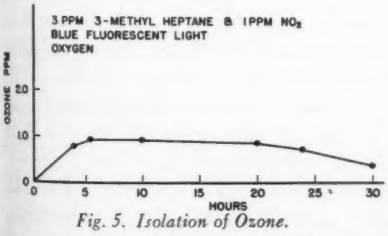


Fig. 5. Isolation of Ozone.

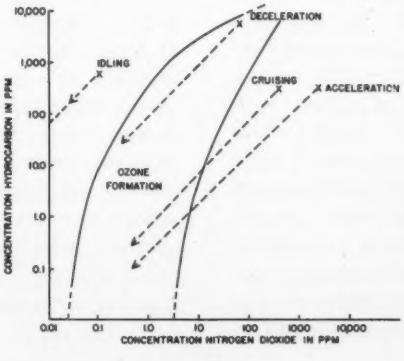


Fig. 6. Photochemical Ozone Formation from Automobile Exhaust. Effective Concentration Ranges.

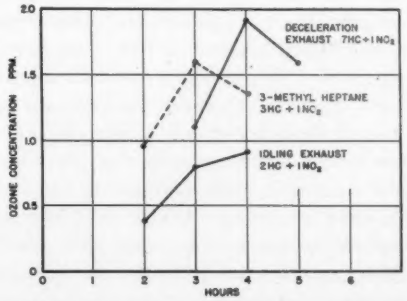


Fig. 7. Ozone Formation with Automobile Exhaust vs. Time.

TABLE I.

Ozone Formation with Automobile Exhaust

Original Sample			Experimental			
Cycle Phase	Composition (ppm.)		Hydrocarbon (ppm.)	NO_2 (ppm.)	Irradiation Time (hr.)	Ozone Found After Irradiation (ppm.)
Cruising	Hydrocarbon	500	0.9	1.1	2.5	0.13
			1.5	2.8[a]	2.75	0.15
	NO_2	611	2.4	3.0	3.1	0.13
			0.9	1.1	5.3	0.15
Decelerating	Hydrocarbon	6,000	6.6	1.1[a]	3.0	1.1
			6.6	1.1[a]	4.1	1.9
	NO_2	75	6.6	1.1[a]	5.0	1.6
Accelerating	Hydrocarbon	600	1.3	6.5	2	0.07
			1.3	6.5	3	0.08
	NO_2	3,090	1.3	6.5	4	0.16
			1.2	6.0	5	0.22
Idling	Hydrocarbon	748	2.4	1.0[a]	2	0.45
			1.9	1.0[a]	3	0.95
	NO_2	0.1	1.9	1.0[a]	4	0.92
			1.5	1.0[a]	5	0.22

[a] 1 ppm. NO_2 added.

The concentrations of hydrocarbon and nitrogen oxides vary with the different phases of automobile operation. Therefore, the exhaust gases from each of these phases (idling, acceleration, deceleration and cruising) were analyzed for hydrocarbon and nitrogen dioxide, and were diluted to provide concentrations appropriate for ozone formation, using the data collected with pure hydrocarbons as a guide.

In order to obtain a hydrocarbon-NO_2 mixture from cruising and acceleration phases which falls within the area where ozone formation was established with synthetic mixtures, the samples were diluted with air to approximately 1/200th to 1/500th of their original concentration. The gas mixture from deceleration, and especially that from idling, is low in NO_2; and since it was preferred to demonstrate ozone formation at concentrations not exceeding 10 ppm. of hydrocarbon, it was necessary to add NO_2 to the reaction mixture. In this manner concentrations were obtained of 2 ppm. hydrocarbon and 1 ppm. NO_2 for idling, and 6 ppm. hydrocarbon and 1 ppm. NO_2 for deceleration. These concentrations are within the range of ozone formation as shown in Fig. 6.

The irradiation was conducted in sunlight and the ozone concentration was determined after varying periods of time. The atmosphere in the flask was composed of synthetic air (80% nitrogen and 20% oxygen, of 30% humidity). After irradiation, the contents of the flasks were passed through traps held at —183° C. to remove nitrogen oxides, as well as peroxides. The ozone passing through the traps was then determined colorimetrically through its oxidizing effect on reduced phenolphthalein. The results of these experiments are shown in Table I and Fig. 7. Also, samples of exhaust gas from decelerating and accelerating phases of the cycle were irradiated with artificial light in an oxygen atmosphere under the standard conditions described earlier, using bent rubber strips suspended in 5 *l.* flasks during irradiation. After dilution to 6.6 ppm. of hydrocarbon and the addition of 1 ppm. NO_2, the exhaust gases from the decelerating phase gave severe cracking of the bent rubber strips, corresponding to an average rate of ozone formation of 1.0 ppm./hr. The exhaust gases of the acceleration phase diluted to 1.1 ppm. hydrocarbon and 5.8 ppm. NO_2 also gave severe cracking, corresponding to 1.0 ppm./hr. of ozone.

It should be noted that during stop-and-go driving, the combination of deceleration, idling and acceleration furnishes an exhaust mixture which contains hydrocarbons and nitrogen oxides in such proportions that no addition of NO_2 is necessary for ozone formation. This combined mixture has substantially the same composition as that obtained from cruising, and we may therefore expect that in both driving conditions ozone formation starts when the proper dilution has been reached. This condition will prevail at some distance from the emission of the exhaust, and it is estimated that a fifty to one hundred-fold dilution of the exhaust is necessary before ozone can be formed through the action of sunlight.

It is also of interest to note in Fig. 6 that exhaust from idling, either by itself or after dilution, does not lead to the formation of ozone upon irradiation, but that NO_2 addition is necessary from other phases of automobile operation or from extraneous sources. This fact has contributed in the past to many failures in the demonstration of ozone formation from exhaust gas.

The concentration of ozone formed, as well as the concentrations of exhaust gases used, are of the same order as those measured in the Los Angeles atmosphere. These investigations show that automobile exhaust gases are capable of forming ozone in the air and are therefore to

(Concluded on page 136)

Selecting Incinerator Smoke and Odor Burners

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Cleveland, Ohio

Flue-fed incinerators such as are used in apartment buildings frequently present a difficult problem in air pollution control. This paper will discuss a method for controlling smoke and odor emission by these flue-fed incinerators. Some of the principles presented here are also applicable to other types of incinerators.

A "flue-fed incinerator" is one in which the stack or flue is used as a chute for delivery of refuse to the combustion chamber. In apartment dwellings the flue extends upward through the center of the building for many stories with charging doors at each floor. Garbage and dry rubbish are dropped down the flue intermittently throughout the day. The operator ignites the pile of refuse periodically (usually once each day). He should turn over the pile of refuse to facilitate more thorough and faster burning. After burning, the operator should rake out the hot non-combustible remains. Otherwise, the fire may smolder continuously from the addition of new refuse. Occasionally bulky bundles get stuck in the flue instead of falling to the refuse pile in the basement. These dry out while suspended and are eventually ignited by sparks or hot gases passing by.

The Burning Process

When the operating procedure described above is followed, burning proceeds from the top toward the bottom of the pile as in a fuel bed fed by an underfeed stoker[1]. However, the hearth is seldom sloped or agitated to provide for removal of the ash from the surface; so, as burning progresses down through the pile, an insulating layer of ash accumulates on the surface, there is no more flaming combustion, and the surface temperature of the bed drops. Due to the heterogeneous nature of the charge, the fire may burn through the dry rubbish, leaving garbage bundles smoldering on the surface. The initial flash burning creates only a minor air pollution problem, but this later smoldering of wet material or of refuse trapped in the bottom of the pile produces very undesirable odors and smoke.

If the operating procedure mentioned earlier is not observed, or if appreciable amounts of refuse are added after combustion has started, burning will proceed from the center or bottom of the pile toward the top as in overfeed stoker[1] or manually fired fuel beds. Air rising through the grate contacts dry material at the ignition temperature and combustion occurs, releasing heat, carbon dioxide (CO_2), and water vapor. These products rise through the pile of unburned refuse, drying it, but also reacting with it. The high temperature and absence of air result in the formation of carbon monoxide ($CO_2+C \rightarrow 2CO$) and the release of volatile distillation products that consist principally of hydrocarbon vapors. (Under continued high temperature and insufficient air, these hydrocarbons "crack," forming black smoke and soot.) All of these products (CO, hydrocarbons, soot) are combustible, but when they reach the air admitted above the bed, they are usually cooled below their ignition temperatures and cannot burn. The result is the formation of a white "smoke" that has a very obnoxious odor. This odor may drift to roof gardens, penthouses, and windows of nearby apartments, or it may even be drawn into the air circulation systems of the same or adjacent buildings. This odor is just as important a problem as are the smoke and fly ash emitted by flue-fed incinerators.

Even with proper operation, white smoke and the accompanying odor cannot be avoided after the initial flash burning if the refuse contains bundles of high moisture content.

Flue-Fed Incinerators Are Different

Not only is the burning process in flue-fed incinerators different from that for solid fuels burning in beds, but it is also somewhat different from that in industrial and municipal incinerators. The bed has a very uneven thickness due to the relatively small chute feeding the pile, and because the pile may seldom be leveled manually. Air admitted below the grate will tend to short circuit through thin sections of the bed (around the edges of the grate), causing the refuse in these areas to burn faster. This makes these sections even thinner and aggravates the unevenness.

There is often alternate up-burning and down-burning, depending upon whether the fire was lighted before or after the deposition of refuse. The mechanisms of combustion for these over-feed and under-feed processes, as discussed above, are radically different.

The surface temperature of the burning refuse pile in a flue-fed incinerator is usually quite low. This, of course, is not conducive to the burning off of odors, and it limits radiation to the refractory surfaces and reradiation to the rubbish pile. Reradiation is most helpful in drying out wet material and in preheating the refuse. Uniformity of burning rate across the bed surface decreases rapidly as reradiation is reduced. The low surface temperature is due to over-feeding, the wet nature of some of the refuse, and the uneven bed thickness which practically eliminates combustion in some areas.

1. "Some Fundamental Considerations in the Design and Use of Incinerators in Controlling Atmospheric Contamination" by Richard C. Corey. (Chapter 46 of *Proceedings of the United States Technical Conference on Air Pollution*, edited by L. C. McCabe; published by McGraw-Hill Book Co. 1952).

A final difference between flue-fed incinerators and other types is the noncontinuous and unpredictable firing and charging. This makes it difficult to estimate and specify burning rates, air openings, and draft.

A Solution

Control of smoke and odor in flue-fed incinerators requires that both *air for combustion* and *high temperature for ignition* be simultaneously supplied to the smoke and odorous gases. Either alone is as inadequate as none at all. (Overfire air alone works well over burning coal beds in furnaces and boilers because the bed surface, the refractory surroundings, and the rising gases are all hot enough to be above the ignition temperature.) The application of air and temperature to the smoke and odors emitted by an incinerator can be done either (1) at the roof, just before their release to the atmosphere or (2) within the incinerator combustion chamber before they enter the flue.

This report is more qualitative than quantitative because it describes a *general* solution on which it is possible to standardize for a variety of units. It is absurd to assume that anyone can provide an individually engineered solution for each of the thousands of flue-fed incinerators all over the United States and Canada. Standardized units with plenty of built-in flexibility will be the surest and cheapest solution in the long run.

Ignition temperature can be provided by use of an auxiliary gas burner placed so that its flame will contact all combustible gases rising from the refuse pile. This need not be a high temperature flame—1500°F is adequate to ignite the odorous distillation products rising from the pile. The combustion air required to burn these gases and vapors must be provided in close association with the gas flame because, as mentioned above, one without the other is useless. The best way to accomplish this is to supply excess air (more than necessary to burn the fuel gas) through the gas burner. Note that this does not necessarily constitute excess air for the burning of the refuse or the gases rising therefrom.

Gas burners to serve the above purpose must be of quite special design inasmuch as they must throw a long flame over a considerable area even though an excess of air is supplied. The solution is to use delayed mixing to produce a *diffusion flame*. The gas and air (including excess air) are caused to leave the burner ports in parallel concentric streams of relatively low velocity. Thus the gas and air streams *diffuse* together slowly with the result that some of the gas travels a considerable distance from the burner port before meeting any air with which to burn, and a long flame is produced. The gas within the core of this flame receives radiation from the flame and "cracks," forming many tiny carbon particles. These become incandescent as they pass through the flame front; so the flame has a luminous yellow-orange color. At points farther distant from the burner port, the action of the flame creates considerable turbulence in the surrounding air stream that was originally quite laminar. This turbulence promotes better combustion of the volatiles rising from the refuse pile. Fig. 1 shows a partial cross-section of a long luminous flame burner and Fig. 2 illustrates a smaller burner with integral blower and controls which was designed to produce the kind of flame needed for incinerators.

Selection and Location Of Burners

Although it is the principal purpose of this paper to describe the procedure for selecting burners, considerable time has been devoted to explanations of how the burner works and how it serves to eliminate smoke and odor.

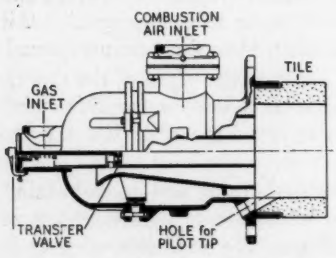
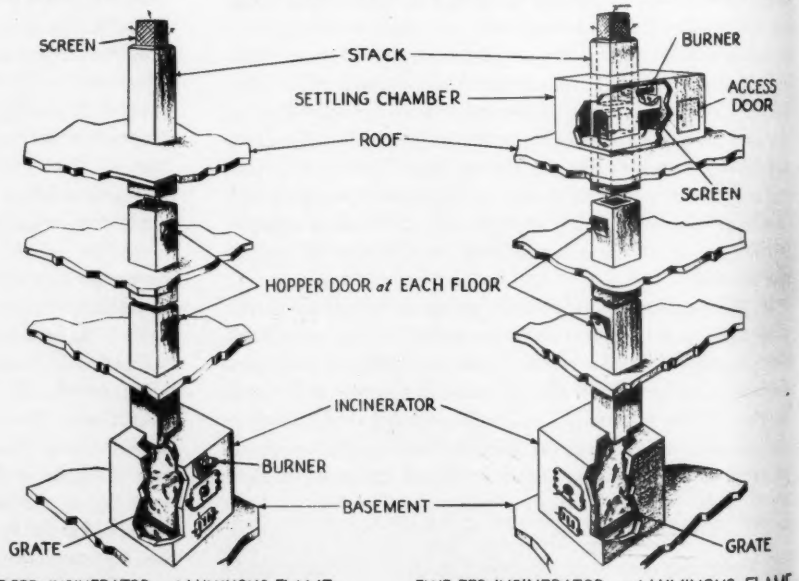


Fig. 1. Partial cross-sectional view of a luminous flame gas burner. A turbo blower is used to supply combustion air. The long luminous flame produced by this burner is ideal for burning off smoke and odors.

Fig. 3. Two methods of installing luminous flame burners to prevent smoke and odor emission from flue-fed incinerators. The settling chamber installation is preferred. →



This was intentional, as the reader by now probably realizes that it is the flame dimension—not the heat release—that is the important criterion. It is necessary to select a burner, the flame shape and flame size of which are sufficient to assure that all gases rising from the refuse material must pass through the flame.

It is not essential that the smoke and odors be forced through a flame immediately after they leave the refuse pile. If a settling chamber is installed on the roof, the gases should be burned at this point by channeling them through a refractory lined passageway into which a long luminous flame gas burner is fired. By making this passageway as small as possible without creating a positive pressure in the settling chamber and flue, the size of the gas burner can be kept to a minimum, thus reducing the first cost of the burner, and saving fuel.

The burner may also be located so as to throw a blanket of flame over the refuse pile. The direction of the flame should be toward the flue so that the widest part of the flame is in a position to cover the area where the most refuse will fall. The flame need not necessarily impinge on the pile, and it is wise to locate the burner port high enough that nothing will obstruct it or the first few feet of flame. Unfortunately, the combustion chamber shape often makes it difficult to cover the area with one flame. Resorting to additional burners or larger burners may result in abnormally high flue gas temperatures. This produces unsafe temperatures at the hopper doors and excess draft that carries out fly ash. The basement installation has the advantage, however, that the additional fuel speeds incineration. Fig. 3 illustrates the roof and basement installations.

Installation of the burner on the roof has these additional advantages: it permits automatic burner operation actuated by a photoelectric cell, and it takes care of smoke and odor produced by material burning in the flue.

Case History Of An Approved Installation

The Department of Air Pollution Control of New York City under the direction of Dr. Greenberg and Admiral Maxwell has been actively engaged in a campaign to enforce air pollution regulations. The flue-fed incinerator with its smoke, odor, and fly ash emission is one of the many violators. The Metropolitan Life Insurance Company has cooperated whole-heartedly with the Department of Air Pollution Control with regard to flue-fed incinerators and air pollution in general.

This paper is an elaboration of a previous one[2] which discussed an installation made at Parklebrea in Los Angeles for the Metropolitan Life Insurance Company. See Fig. 4, 5, and 6. After the successful completion of the smoke control program in Los Angeles two and one half years ago, Metropolitan Housing engineers continued experimenting with and testing the application of gas burner equipment and the use of settling chambers at the New York housing developments—Parkchester, Peter

2. "The Application of Gas Burner Equipment for Eliminating Smoke and Odors from Flue-Fed Incinerators" by S. M. Truitt (North American Reprint No. 24).

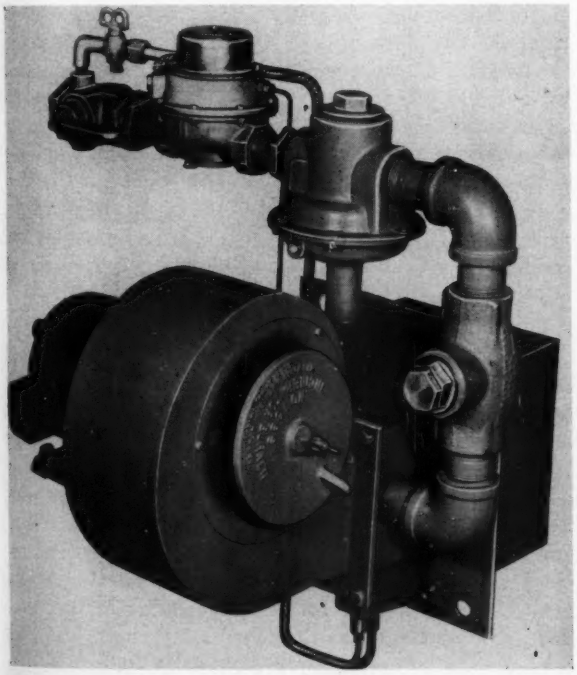


Fig. 2. An incinerator burner unit complete with gas controls, safety pilot, and combustion air blower. Burners (such as this) that produce a luminous flame are readily adaptable to the use of excess air, an essential feature for air pollution control in incinerators.

Fig. 4. Parklebrea Housing Development, Los Angeles, California, built by the Metropolitan Life Insurance Company. Arrows point to settling chambers with burners for eliminating smoke and odors. Fig. 5 and 6 show close-up views of a settling chamber and burner.

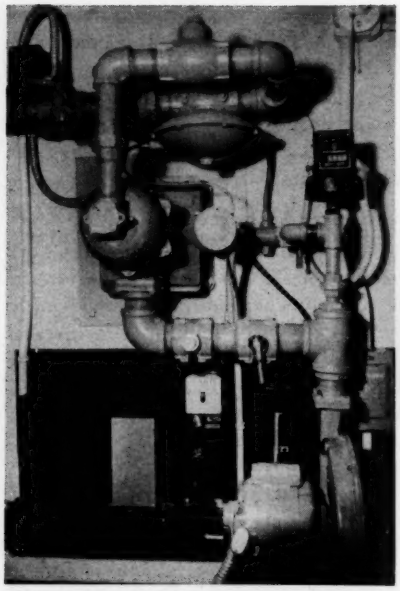


Fig. 6. Close-up view of burner equipment seen in Fig. 5. Equipment shown includes Luminous Flame Burner with Spark-ignited Gas Pilot and Flame Monitoring Rod; Turbo Blower, Regulator, Valves, and Controls.

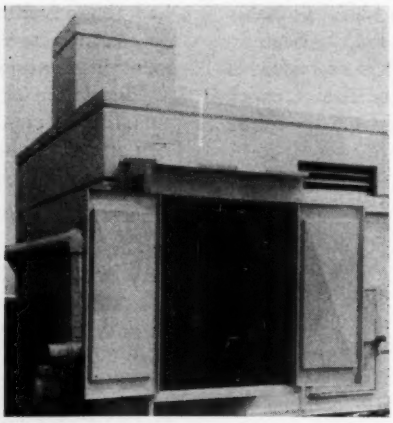


Fig. 5. Roof-top settling chamber at Parklebrea. Panel doors are open to show gas burner equipment.

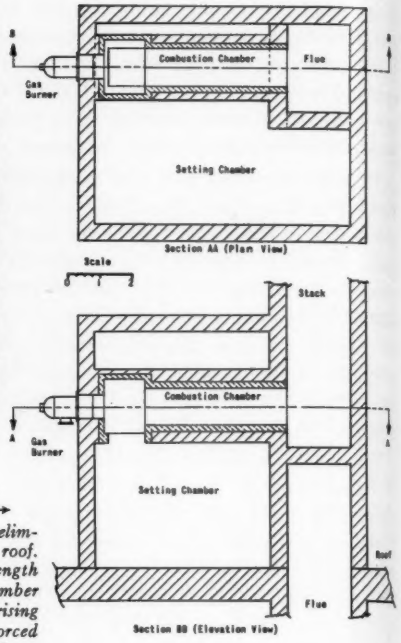


Fig. 7. Combustion chamber for the smoke eliminating gas burner when installed on the roof. The flame fills the entire length of this refactory-lined chamber so that all volatile matter rising from the refuse pile is forced through the flame and burned.

Cooper Village, Stuyvesant Town, and Riverton. The solution of the problem on existing flue-fed incinerators is not one to be derived from the application of a fixed formula, nor could it be attained from previous experience because of the wide variation in construction, location, and loading. This accounts for the length of time required to reach a satisfactory solution. A brief review of Metropolitan's solution of the problem follows.

Exhaustive tests were made with the burner equipment located both at the incinerator and at the settling chamber. As far as these installations are concerned, the advantages of the settling chamber location far outweighed the basement location. It should be noted that none of these Housing projects was originally equipped with settling chambers, but they will be incorporated in the overall solution, and will play a most important part in that solution. The reasons for selecting the settling chamber installation were:

1. From actual tests the most efficient control of smoke and odor was obtained with the burner at the settling chamber.

2. It has been estimated that the cost of operation of this equipment will be approximately $490 per year for each unit, or about 41c per month for each suite served. Needless to say, the most economical location of burner equipment should be selected so far as is practical.

3. Excessive temperatures at the first floor hoppers, such as would be possible with burners at the incinerator, could not be tolerated because of the hazard to the tenants.

4. Smoke control could be obtained even in the case of flue stoppages or burning in the flue or if rubbish piles up in the flue. This would not be true if the burner were located at the incinerator.

Settling Chamber and Combustion Chamber

The settling chamber design finally decided upon employs a 90° chamber wherein the flue products enter the chamber from one side of the flue, travel around and re-enter the flue above and at 90° to the point of entrance, the points of entrance and exit in the flue being separated by a baffle plate. The flue products travel through a specially designed cylindrical combustion chamber prior to re-entering the flue, as shown in Fig. 7. The diameter of the opening and the length of the combustion chamber were selected to match the size of the incinerator and the peak volume of gases to be heated. For fuel economy the combustion chamber was kept as small in diameter as possible without creating back pressure in the flue[3].

The Burner

A luminous flame burner (previously described) is used to give a long, highly radiant type of flame, making it possible to keep the flue gases in contact with the flame and subject to the radiant heat of the flame for the entire length of the combustion chamber. The burner, which is adjustable for various capacity ratings, is equipped with approved flame safety devices, air and gas pressure failure switches, and automatic gas-electric ignition. Each unit is provided with indicator lights and push button starting and stopping from the incinerator location in the basement or from the burner location on the roof.

Starting Procedure

Before lighting off the incinerator the operator starts

3. "COMBUSTION HANDBOOK" by North American.

the burner equipment by push-button from the basement to allow the combustion chamber to preheat for a few minutes. (Preheating is desirable but not necessary). Placing the start-stop switch in the "on" position starts the combustion air blower, completes the circuit through the air failure switch and energizes the flame safety device. The pilot solenoid valve and pilot transformer are energized for a 15 second ignition period during which time the main burner ignites. Signal lights in the incinerator room indicate proper or improper operation of burner equipment at the settling chamber. Placing the start-stop switch in the "off" position shuts down the entire burner system.

New Installations

It was announced on March 18, 1954, in the New York papers that Metropolitan was embarking on a 2½ million dollar program of smoke control on their flue-fed incinerators. Actually there has been a test unit in successful operation for the past several months in each of the four housing developments. See Fig. 8, 9, and 10.

The installation of smoke, odor, and fly ash control equipment at the Metropolitan Housing projects is expected to take approximately 18 months and represents the largest installation of flue-fed incinerator smoke control equipment ever undertaken.

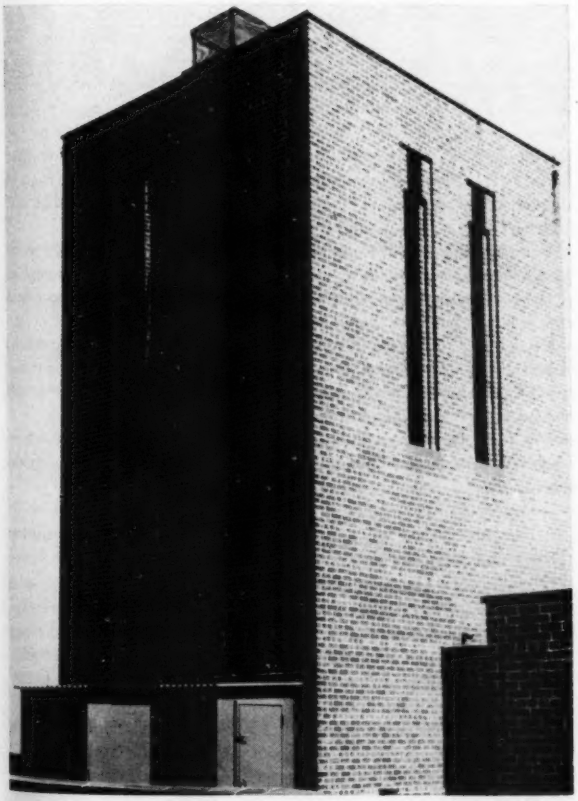


Fig. 8. Experimental roof-top installation at Parkchester Housing Development in New York. The combustion equipment and settling chamber are housed in a metal lean-to. The stack is concealed by the same superstructure that conceals a water tower.

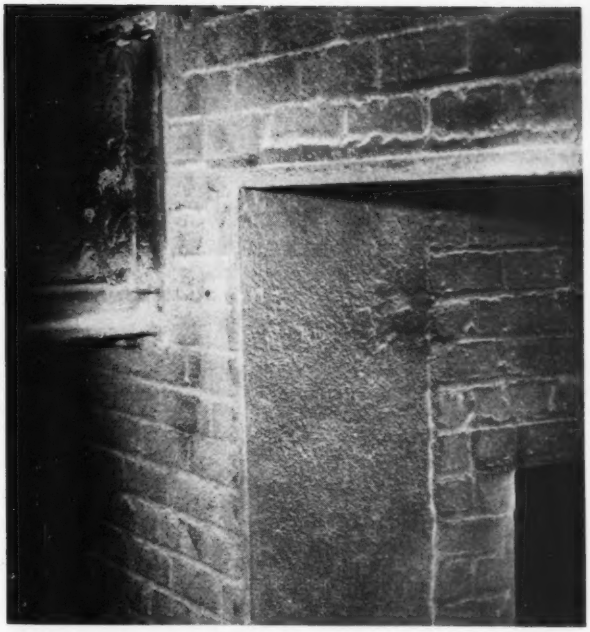


Fig. 9. Interior view of the flue entrance to the settling chamber of the unit shown in Fig. 8. The "duct" at the upper left is the combustion chamber, which is connected to the stack.

DISCUSSION OF PAPER BY R. J. REED AND S. M. TRUITT ENTITLED "SELECTING INCINERATOR SMOKE AND ODOR BURNERS"

To cover the subject suggested by the title of the paper would require much more time than could be allotted to a paper here so the authors wisely narrowed their subject to a most troublesome type of incinerator, the flue-fed, and after a discussion of the burning characteristics of this type of incinerator, worked out a solution to a specific case. In doing so, they have skillfully produced a paper which is a pleasure to read and which displays considerable knowledge of combustion. This paper should prove a valuable reference for Air Pollution Control Officials beset with odor nuisances from so-called incinerators and with the task of approving installations of fuel burning equiment. Of particular interest to us is the simple instructive description of how a diffusion burner works.

Under the subheading "Selection and Location of Burners" it seems, however, that the authors have achieved oversimplification. Even

Fig. 10. Aerial view of Parkchester, one of four developments in New York that will be equipped with settling chambers and luminous flame after-burners. The experiments described in this paper were conducted at this site.

though the primary combustion area cannot be covered with one flame, could not several burners be so sized that just enough heat is supplied to maintain combustion without abnormally high flue temperatures, or at least no higher flue temperatures than result from rapid combustion of dry paper and trash? Could not burners in the basement be actuated by the same photoelectric cell located on the roof? If so, this leaves only the additional advantage for the roof installation that it takes care of smoke and odor produced by material caught and burning in the flue, which may be a big advantage depending on the location of the building.

Since the best location for the auxiliary burner in the case history discussed was determined after exhaustive tests, the results can hardly be questioned but it would add to an already valuable paper to go more into detail about these tests. For instance: 1. Were any tests made with lower capacity burners in the incinerator and in the settling chamber operating at the same?* 2. Can all the garbage be completely burned without an auxiliary burner in the incinerator? 3. If high temperatures at the first floor hopper are a real hazard, could not the first floor hoppers be locked during burning periods to permit more economical location of the auxiliary burners? 4. How much material is actually collected in the settling chamber?

Answer to these questions would certainly be of additional help to control officials.

*Apparently the writer meant to say either "at the same time" or "at the same heat input rate". (author's comment).

RALPH W. BOURNE,
Air Pollution Control District
Jefferson County, Ky.

Answers to Mr. Bourne:

The authors wish to thank Mr. Bourne for his comments and compliments.

The suggestion that perhaps a number of small burners could be used in the incinerator without abnormally high flue temperatures is a good one. We frequently use a number of small burners in industrial furnaces to achieve better heat distribution. However, in this case, we are striving for flame distribution. The nature of the diffusion flame, with its annular ring of excess air is such that for two small flames to cover the same area as one large one, the total fuel input would have to be greater than that for one large flame. The ratio of the gas-air interface area to the volume of fuel is greater for small burner nozzles; hence the fuel burns within a smaller space and the flame coverage is less.

Yes, burners in the basement *could* be actuated by a photoelectric cell, but burners on the roof have the advantage of the time delay that occurs while the smoke travels from the basement to the roof; so the first trace or even single puffs of smoke can be burned off. The authors feel that it is only fair to point out, however, that photocell installations to date have not been successful because of the accumulation of grease on the lens which causes the burner to operate all of the time.

The following numbered paragraphs contain the answers to Mr. Bourne's numbered questions regarding the experimental units.

1. No tests were conducted with lower capacity burners operating simultaneously in the basement and settling chamber. For the case cited in the paper, any smaller burner in the settling chamber would not have burned the smoke and odor completely. However, the authors see no reason why an ignition burner could not be added in the basement to speed incineration. To try to burn half the smoke and odor in the basement and half at the roof would not seem to be wise as the roof burner might burn the wrong half.

2. Under more or less ideal conditions—such as a properly designed incinerator, proper loading, balanced ratio of dry to wet refuse, proper mixing of dry and wet refuse, and proper control of air into incinerator —complete combustion of the refuse without an auxiliary burner in the incinerator should be obtained.

3. The first floor hoppers could be locked during burning periods to permit installation of the burner in the basement if the owner and tenants agree to it, but care would have to be exercised to see that the exterior surface, including handles, were not too hot.

4. The amount of material collected in the settling chamber is such a variable depending upon so many conditions that it is almost impossible to make a general statement. Even the nature of the material collected will vary from just "fly-ash" to "fly-ash plus complete sections of newspaper." Some items do not even get to the incinerator but go up to the settling chamber. The amount of draft and the degree of complete combustion in the incinerator will determine the amount of material in the chamber. These two items alone will vary greatly from one incinerator to another. Weather conditions also will affect the operation of the unit and hence the amount of material in the settling chamber.

The authors appear to have been concerned mainly with buildings with high flues. However, there are a great many installed flue-fed units with relatively low flues, and one might question the solution offered by the authors in these cases, since the draft problem is not so great.

One school of thought holds that once-a-day burning is the main reason for nuisance complaints. Some confirmation of this idea may be found in the work at Cleveland where there has been some success by allowing more frequent burning, or around-the-clock burning. Pittsburgh also advocates extended burning periods. Extended firing periods avoid high flue temperatures and excessive stack drafts. In Columbus, Ohio, the Metropolitan Housing Authority ran comparative tests in a number of different burners in flue-fed incinerators and it is my understanding that the best results were obtained with timer controlled, intermittent firing periods.

When the speaker talks of bulky bundles which stick in the flue and burn there, he is stating as part of the basic problem what is a basic fault in design. There is a strong desire on the part of some building owners to have large hopper doors and small flues which seems to be based upon the idea of securing lowest cost with greatest convenience to the tenant. Even the recommended ratio of 1:2 or 3 in size of door to size of flue is not wholly safe, but it is better than frequently is provided for. At any rate this is a function of design of the structure and not of auxiliary provisions to prevent smoke and odors.

Some thought has been given to the use of preheated air to avoid smoke and odors, this might appreciably reduce the overall cost of smoke elimination, and it would be appreciated if the authors would express their views in this connection.

Considering the number of buildings that potentially would be served by the burners that the authors recommend, installation cost of $165,000 seems almost prohibitive. It would be very difficult to get owners to pay such high capital and operating costs.

Regarding the hazard to tenants from hot charging doors, the New York City Authorities now insist on an insulated door with an insulated handle.

FRED W. DONLEY,
The Donley Brothers Company

Answer to Mr. Donley:

It is correct that the authors have been principally concerned with tall buildings. However, luminous flame burners *are* operating successfully in buildings with relatively low flues. In the latter case, the cost relative to the smaller number of suites served and the smaller grate area would suggest that it is best to resort to installation of the burner in the basement.

The idea of a small burner in the bottom of the chamber operating 24 hours per day for drying and igniting the refuse is an admirable attempt to stop pollution at its source. The authors have no doubt but that it prevents a lot of the pollution resulting from a large accumulation of refuse (too thick a bed for practical control). The use of a continuous or intermittent burner in the bottom of the chamber is an excellent way to increase the capacity of an undersized or overloaded

chamber. However, wet garbage bundles will smolder and produce a bad odor, and discarded plastic, rubber and waxed containers will produce a thick smoke despite the use of a drying and ignition burner; so a "policeman at the gate" is still the best insurance against creating a nuisance.

Preheating air to the ignition temperature of the fumes would most certainly dispose of the fumes. To utilize the waste heat in the refuse chamber, however, would require too large and expensive a heat exchanger. The only practical means for preheating the air would be a direct-fired air heater. This is essentially the solution described in this paper, except that the air preheater has either been telescoped into the refuse chamber or inserted into the flue to save space.

$165,000 is not the installation cost but the estimated annual operating cost for 300 incinerators, each serving about 100 suites; thus as stated earlier, the operating cost will be about 41c *per month* for each suite. In this connection, it is interesting to note the following discussion excerpted from Mr. Hoyt R. Crabaugh's letter of June 25, 1954 to the authors.

In discussing your paper at Chattanooga, I stated that although we have not made a stack analysis at Parklabrea, we would *estimate* that solid products of combustion from the incinerator stacks do not exceed 0.2 grains per cubic foot of flue gases with the CO_2 content adjusted to 12% by volume. I further stated that visible smoke and odors from the incinerator stacks were negligible and unobjectionable. As you will recall, however, I qualified my comments by specifying a gas firing rate to the afterburner equivalent to 650,000 Btu/hour.

According to data received . . . on June 4, 1954, the natural gas rate to the incinerators is now about 440 cubic feet per hour.

Due to the discussion on costs given at the convention, the following data may be interesting: Based on one and one-half hours per day operation, a gas rate of 440 cubic feet per hour, a cost of 45 cents per thousand cubic feet of gas, and 78 apartments per incinerator; the cost of gas would amount to about 0.38 cents per apartment per day or $1.39 per apartment per year.

HOYT R. CRABAUGH,
Air Pollution Control District
Los Angeles, California

The papers presented both point up a considerable step in the improvement of the sad state of the flue-fed incinerator. Ring burners or nozzle mixing burners have been successfully employed in several applications in the incinerator industry. We caution against the situation of a positive pressure within the chimney-flue, however, when using any device restricting the area of the chimney-flue or creating other draft losses. Even settling chambers when used without burner or filter usually require an extension of the chimney.

The flue-fed incinerator has long been recognized by engineers to be faulty in principle. The papers presented have already indicated some of the fundamental errors. Originally we were engaged only in the design and construction of Class III* to Class VII* incinerators (destructors) and I can recall how reluctantly my father—the late Mr. Joseph Goder conceded to the economic demands to design as well as could be, flue-fed incinerators.

Perhaps the day has arrived when the flue-fed incinerator is no longer economically sound. Certainly many factors are present now that were not considered twenty years ago—and that even today are being ignored. Air pollution control has very drastically tightened. Ventilating and air conditioning systems have created mechanically induced vacuums or pressures within the newer buildings.

These and many other factors may change the emphasis on Class II-A (flue-fed) incinerators. Certainly the papers presented demonstrate that improvements have been made to relieve the nuisance inherent with this class incinerator but they are in the nature of treating the symptoms rather than curing the disease.

In comparison with the old conventional single-flue incinerator, a unit as described in the papers presented including settling chamber and filter equipment or settling chamber and secondary burner; the initial cost of a new installation will just about double in price. Added to this cost is the new cost of fuel, power and maintenance of mechanical equipment.

We are ready and willing to make such installations but feel that all concerned should recognize the costs involved and be ready to offer an alternate solution namely, the use of an efficient Class III incinerator installed in the boiler room that will be under the supervision of the engineer and can utilize the boiler chimney. In conjunction with such an installation a refuse chute may be used to carry the refuse from the several floors to a central container or refuse receiving room where the refuse is charged into incinerator. Such installations are in operation in Chicago, Birmingham, Los Angeles and other cities.

*Classifications as designated by APCA Committee on incinerators. Minutes of Annual Meeting 1950.

RICHARD GODER,
Joseph Goder Incinerators

Answers to Mr. Goder:

Concerning Mr. Goder's caution against positive pressure within the flue, it is important to note that this was the principal problem in the experiments described in the paper. It would not have been so large a problem had it not been that a single combustion chamber and settling chamber design was sought for a variety of buildings. The buildings were of different heights and consequently the incinerators had different drafts and different loadings. It is important to remember that the hotter gases in the stack above the burner will create more draft, somewhat offsetting the loss due to the combustion chamber. It is suggested that a small bypass from the settling chamber directly to the stack could be built into the original construction. The high temperature in the stack just above the combustion chamber outlet is sufficient to burn off smoke and odor in the bypassed gases. Then, by trial and error, this opening can be plugged with enough brick to permit reduction of fuel cost without creating a back pressure.

The authors would be the first to agree that the flue-fed incinerator is far from ideal and that new buildings might better be equipped with a Class III incinerator as original equipment. It should not be implied, however, that this type of incinerator may not require secondary burners for removal of odors or settling chambers for removal of paper ash. The principal objective of the project described herein was to find a satisfactory correction for the thousands of nuisance-creating flue-fed incinerators already in use in buildings where there is no space for a more efficient type of incinerator.

This paper is a valuable contribution to the knowledge of incinerator operation and particularly the requirements for reducing odors. It is especially valuable because the information is developed from extensive field investigation rather than theoretical considerations.

Of interest is the point made several times that heat release is less important than the burner flame size and shape. It is well to note that the fume burning unit in the settling chamber on the roof should be held small as possible. Evidently the time of burning is not as important as intimate mixing to insure that all products of combustion from the incineration process actually pass through the wall of flame.

However, it is disappointing that the authors were not able to present design criteria for a fume burning chamber based either on theoretical combustion data or upon their experience gained during the development of the Metropolitan Life project. It is obvious that the owner of the average apartment building could not stand the expense of such elaborate tests as described herein in order to select and determine the proper equipment and sooner or later there will be need for design criteria for the fume burning chamber of a chute fed incinerator.

There is no mention in the paper of the effect of the burner on the

carry over of fly ash through the chamber and out the stack. Some mention of this effect would be helpful as it is well known that the application of a burner in the combustion chamber of the incinerator aggravates the ash carry over considerably.

It is again said that the authors are to be complimented for this valuable addition to incinerator knowledge.

CHAS. W. GRUBER,
Bureau of Smoke Inspection
Cincinnati, O.

Answers to Mr. Gruber:

As stated earlier, a general solution was sought in the design of the combustion chamber. It is hoped that the selected design will serve a somewhat broader range than the 8 to 12 stories served at the Metropolitan Life developments. However, the by-pass arrangement suggested in reply to Mr. Goder permits even more flexibility than that built into the design; so experimentation on the part of the owner would be minimized.

With regard to the combustion chamber on the roof, we have never observed any increase in fly ash carry over with the use of a burner at this location.

When the burner is installed in the combustion chamber, an increase in fly ash up the stack will be noted due primarily to an increase in draft because of increased temperature difference. It is interesting to note, however, that opening the cleanout door in the incinerator will increase material up the flue—with or without a burner.

Messrs. Reed and Truitt are to be congratulated for a paper which is an excellent contribution to the engineering of incinerator combustion. The criteria of good burner design for odor and smoke elimination is clearly presented and should be of great value to the practicing engineer who may be called upon for technical advice on incineration.

As a contribution to the combustion technology presented in this paper, I would like to mention the findings of the laboratory incinerator* tested by the School of Mineral Industries of the Pennsylvania State University. The refuse in this incinerator was burned on a refractory floor (no grate type incinerator) by burners located in a horizontal position and inserted through holes in the refractory walls. In addition the gases from the burning refuse were passed over refractory spheroids located on top of the incinerator which were heated by burners. This was found to eliminate the smoke and odors emanating from the refuse bed. Also, it was found that the percentage of combustibles remaining in the residue was less in this no-grate type incinerator. A hotter burning zone for the no-grate type incinerator compared to the cold zones produced by a grate was found to be responsible for the complete refuse destruction.

*New-Design Household Incinerator Eliminates Smoke and Odor. L. T. Bissey, *(Gas Age, p.30, August 5, 1948)*

ALFRED KOESTEL,
Case Institute of Technology

Answer to Professor Koestel:

The authors wish to point out that heated solids such as refractory spheroids and cast iron checkerworks inserted in the flue operate on the same principal as the luminous flame in that they provide ignition temperature and (sometimes) mixing. They do not, however, provide excess air, and they usually cause a greater draft loss. The authors wonder if the additional cost of installation and maintenance on the solid surfaces would not cancel the saving achieved through the use of a cheaper auxiliary burner.

The papers presented by Mr. Reed and Mr. Gabbert describe the results of intelligently engineered installations for reducing or eliminating the nuisance from smoke, odors and fly ash from flue-fed incinerators. Such interest and active effort by manufacturers of equipment of the types required will hasten the correction of the difficulties in a majority of the installations now in existence.

The flue-fed incinerator as originally conceived and designed by Theodore Kerner was to consist of a flue with hopper doors, and a burning chamber in the basement of adequate size for accumulation and storage of the refuse for a day or even preferably for several days. After the refuse had reached the propere level, the fire was to be lighted from the top, and air admission was to be so regulated that the burning would proceed downward to the grates at a slow rate. Volatiles released, as the burning level was lowered, traveled up thru the flames, and complete combustion was obtained. Apartment chimneys were comparatively low, and with the low temperatures of the gases in the flue, due to the fact that there was usually considerable excess air over the fire—this was the purpose of the Kerner Bypass Grate—drafts and velocities were low, and operation, even by today's standards, was usually acceptable. Many of those older installations, if operated in accordance with instructions, are giving satisfactory service today.

And then what happened—not suddenly, but through the years—food packaging and buying habits changed. People read more papers and magazines. Wastes contained less moisture and therefore more heat. Many apartments were higher. Due to space limitations or competitive designs, burning chambers were smaller in proportion to the daily accumulation so more frequently a nearly continuous burning took place. Janitor or caretaker labor cost more and cared less. However, the advantage of incineration on the premises became so well recognized that there is no doubt that flue-fed incineration is here to stay.

For many years, an order from a general contractor or owner to an incinerator manufacturer for a flue-fed installation consisted of grates, access doors, hopper doors and a plan. Any effort to add as much as a single gas burner received strong resistance from the architect, builder and owner. Too often the preference was given to the manufacturer whose plan called for the least space in the basement, as well as the lowest price. Now owners of large apartments and developments are willing to consider a considerable expenditure for capital investment and for operating cost to retain the advantages of flue-fed incineration. The adoption of proper minimum standards for capacity and design will reduce the number of nuisance installations, and simplify the matter of adding auxiliary equipment when considered or found necessary.

The papers presented covered the cures applied to existing installations, but the equipment and methods used may also be used in new installations. There is little doubt that treatment of the gases at roof level or at least above the top hopper door is, in most cases, preferable to attempting to remedy conditions in the basement. In many cases, it represents the only possible solution. There usually is little or no space available for expansion—horizontally or vertically. Slower burning, in accordance with the original concept, is often impractical and sometimes impossible. Higher flue temperatures in the existing construction would often not be permissible. There are of course difficulties to the installations at roof level, such as providing gas, electricity and sometimes water, space limitations and the support of the structure. However, these difficulties can usually be overcome.

So, with this discussion of the problem and its background, let us consider the solutions presented. The first equipment described consists of a burner for the smoke and odors, preceded by a settling chamber. There is no doubt, theoretically or practically as proven in thousands of applications, that smoke and odors, which result from the incomplete combustion, can be burned. Settling chambers, properly sized, should and in most cases have, reduced fly ash to acceptable minimums. So, this solution combines two accepted methods, and its application in any individual case depends upon adapting it to the existing conditions.

I was particularly interested in the statement that "both *air for combustion* and *high temperature* for ignition must be simultaneously supplied." I agree, but I would have expected that there would normally be, under low temperature operation, in the gases several times the amount of oxygen required for combustion of all the com-

bustibles in the wastes, and many times the amount required for the unburned volatiles at roof level. The changes in velocity and the turns in passing through the settling chamber should have resulted in adequate mixing. If however, the temperatures obtained in the incinerator, and the degree of smoke at the chimney indicated a deficiency of air, then the added supply at or ahead of the burner would be necessary.

High temperature is a relative term, but the temperature must admittedly be high enough for ignition. If however, actual flame contact is considered necessary for ignition, why would not a short bushy oxidizing flame be equally effective and more economical? Is not the radiant flame selected because it transmits more heat by radiation to the gases and to the surrounding refractories? Furthermore, can flame contact or radiation or conduction raise the temperature of the combustible gases to ignition temperatures without raising the temperature of all the surrounding gases to the same temperature? I raise these questions, not in any doubt of the success of the operation, but to try to find any explanation for myself, and possibly for others, as to why flame dimension is of more importance than heat release. Possibly to maintain the flame dimension, particularly when the flame is surrounded by gases with close to normal oxygen content, the heat input is adequate to raise the temperature of all the gases to the ignition temperature for the combustibles. And, although my company has for decades advocated operation at 1200° to 1250° as desirable, we will be the first to agree that there is an ample safety factor at that temperature and that most of the hydrocarbon gases have ignition temperatures in the range of 700° to 1100°.

The experiment described by Mr. Gabbert is of particular interest in that it included 3 methods of collection, namely, filtration, electrostatic precipitation, and spray and wet contact removal combined with centrifugal action. In one test, on a weight basis, the efficiencies greatly exceeded 99% by weight. With another combination, over 90% by weight of the solids was removed. These efficiencies show that equipment in use on other types of dust collection can be applied to the incineration field, although temperature limitations may require pre-cooling of the gases and selection of special materials, or both.

The big question of course is—what did the 1% or 10% which get by represent in weight and particle sizes? Would the operation be acceptable, both to the public and to any existing codes on solids emission? I would have little doubt, that, with proper design and operation of the incinerator, 90% removal should be acceptable.

And now in this matter of acceptability to codes, let us consider the type of solids emission code which now seems to be most popular or rather which seems to be most frequently included in ordinances—probably because of its availability rather than its popularity. Briefly, solids shall be limited to .85# per 1000# of gases corrected to 12% CO_2.

Let us assume an apartment house has a coal-fired boiler with 9000# flue gas per hour at 12% CO_2 and emitting, whether with or without fly ash collection, 7.65# of solids per hour. 7.65÷9= .85#/1000# gases, acceptable under the code. There is also a flue-fed incinerator with 3000# flue gas per hour, at 4% CO_2 and emitting, whether with or without fly ash collection .9# per hour. .9÷3=.3# per 1000# gases multiplied by 3 for correction to 12% CO_2= .9#/1000# gases, not acceptable under the code. There has been no deliberate dilution of the flue gases, yet there is a violation of the code due to a concentration of solids in the incinerator gases only 35% of that in the boiler gases, and a solids emission weight per hour less than 12% of that from the boiler. If the 12% CO_2 correction factor was included to prevent deliberate dilution of the gases after they leave the boiler—and I cannot think of, nor have I heard of, any other reason, would it not be comparatively simple to include a check on such dilution as a part of a test? A CO_2 reading at the boiler outlet compared to one at the test station would show whether there was intentional or accidental dilution of the gases. Why set up a double standard for the honest people in order to catch a dishonest operator? Why *not* base performance on true solids concentration rather than on CO_2 deficiency?

In conclusion, I wish to compliment the authors on the papers which they have presented and on the able work done which preceded the papers.

HERBERT W. LINCOLN,
Morse Boulger Destructor Co.

Answers to Mr. Lincoln:

It is true that considerable excess air *may* be present at the burner due to natural draft, but, of course, it is not certain. No flame as effective as the diffusion flame for this purpose has yet been devised without the use of a power burner (blower air supplied through the burner). The directed stream of air is especially important where the burner is installed in the incinerator because of the tendency of induced air to stratify and not mix with gases rising from the refuse pile.

There is little doubt but that raising all the gases to a temperature above their ignition temperature would burn off the smoke and odor. However, a luminous flame large enough to cover the required area invariably satisfies this requirement, while also assuring much more complete contact between the gases to be burned and the hot combustion products or flame. It might be difficult to design a combustion chamber for thorough contact between the volatile matter and a short flame without creating a large back pressure. A short flame is seldom bushier than a diffusion flame of the same heat input.

I wish to congratulate the authors of this paper for presenting a very interesting report on the flue-fed incinerator.

There are several things concerning this report about which I would wish further information. Mention is made of an estimated cost of operation of this equipment of approximately $165,000 per year. Does this cover the cost of one flue-fed incinerator or numerous installations?

The second problem: It is apparent, with this fuel cost, that you must consider operating this equipment a considerable portion of the time. As explained in the report, it is operated by manual push-button controls and it is mentioned that automatic controls prove unsuccessful. Have you experimented with a timing device to operate it for ten minutes on a half-hour or one-hour program?

We in Cleveland have utilized this sort of timer in conjunction with an ignition burner and had fair success with it. By operating the incinerator ignition burner for ten-minute periods on a half-hour program, material does not accumulate in a combustion chamber to such a point that the effluent from the incinerator stack ever becomes a nuisance. The ignition burner also dries out the material as it is deposited, and when it becomes dry enough, is ignited. We have over 100 such installations of this nature in Cleveland, and when given proper attention they have not created a nuisance. It appears that the human element is the most difficult to control in the operation of a flue-fed incinerator and without overcoming the manual push-button operation, this equipment will not function without creating a nuisance.

We wish to thank the authors of this paper for their work and their presentation.

HOWARD J. SCOTT,
Division of Air Pollution Control
City of Cleveland, Ohio

Answers to Mr. Scott:

The operating cost of $165,000 per year is for 300 incinerator units at $450 per year for each. This is equivalent to about $1.50 per day for each unit, which is the cost of 2½ hours operation at a rate of 600 cfh.

The advantages and disadvantages of a continuous or intermittent drying and ignition burner are discussed in answer to Mr. Donley.

The Smoke Picture of Today

W. H. Fortney
New York Central Railroad
Indianapolis, Indiana

Railroad smoke of today is nearly a thing of the past. We all know this was brought about by "dieselization" on the railroads.

It is a very hard job today to write a paper on railroad smoke without including some duplication of items presented before. Smoke abatement on the railroads as a whole is becoming less necessary day by day, in so far as the steam locomotive is concerned.

Smoke abatement is not a one-man job. It is everyone's concern. Although most of the railroads are correcting this nuisance and in a few years will be entirely smokeless, we will still have the problem of air contamination. As long as coal is burned there will be some smoke; that is, until all concerned with burning coal are educated and all smoke consuming devices are corrected to burn it smokelessly. The railroads have done a tremendous job of burning coal smokelessly.

In most major cities open dumps can be found, some of which are usually found to be afire. Is there any source of nuisance as bad as a smoldering, smelly, dump fire? Railroads have oftimes been accused of smoke nuisance originating from what is later found to be a dump operating in close proximity to a railroad yard or trackage.

Railroads have in the past been great offenders in air contamination; in other words, smoke. But thanks to the wholehearted cooperation of the air pollution engineers and the willingness of the railroad supervisors to work with them, it has been possible to make a great improvement. Also, dieselization has had a great bearing in helping all concerned to combat this nuisance.

We have on the New York Central System some 85 towns that have smoke ordinances, some being more drastic than others. We also have many towns or points that do not have smoke ordinances, but the railroads' campaign on fuel saving made it just as important to abate smoke over the entire New York Central System as it was to abate smoke in places where we had ordinances. It has been proven for many years that smoke wastes fuel dollars, and we had to educate the engine crews, as well as the round house forces, along these lines.

Our railroad has no hand fired road locomotives operating today, but we still have a considerable number of hand fired yard locomotives, all equipped with smoke consumers. All road steam locomotives are equipped with stokers and smoke eliminating devices. The fuel is much better today than we were able to buy a few years back, due to a lesser demand for fuel coal.

Today with most of the railroads dieselizing and the New York Central 75% dieselized, the demand on fuel is lessened. Therefore, we can demand good fuel for locomotive use for the few steam locomotives that we have left. It is now understood that the New York Central will be completely dieselized within the next two years.

Dieselization of the railroads has answered the problem of smoke abatement to some extent, but I wonder just how long after steam locomotives are a thing of the past that we will get complaints about the noise, fumes, and horns on the diesel locomotives. Also, part dieselization on any railroad creates a hazard on smoke abatement for this reason: where we have 75% diesel and 25% steam locomotives operating, men have a tendency to get careless because they operate diesel locomotives most of the time and get a steam locomotive only occasionally. This also calls for constant supervision.

I can remember in 1938 when the English train known as the "Royal Scot" visited the United States and toured over our American railroads, operated by English crews. This was a beautiful train, including the hand-fired steam locomotive.

I was assigned to ride this train, and was greatly impressed with the efficiency of the locomotive. If the American steam locomotive builders would have experimented and built locomotives such as this type, I believe that the steam locomotive would have a prominent place in railroads of today, whereby they would have had fuel economy that would compete with any diesel, electric locomotive for economical performance.

It is generally recognized and conceded by those directly connected with smoke abatement and air pollution in campaigns throughout the United States that the railroads are not the principal source of air pollution. This is more true now than in years gone by, due to dieselization. The railroads have actively participated in movements in various communities to combat the smoke nuisance. This is still the program of all railroads.

My observation of air pollution today leads me to believe it is not due to smoke from the railroads, but smoke from industries and private homes, especially in the winter months. When we can educate the private home owner or renter who burns coal for heat to become smoke minded and have a little consideration for his neighbor by firing his coal burning appliances smokelessly, we will eliminate a lot of air pollution in our fair cities and towns.

Other air pollutants, such as fumes from autos, buses and trucks, not necessarily seen, can do a great deal of harm to public health through air contamination. It is my opinion that carbon monoxide released by gasoline-burning vehicles is more injurious to public health than

(Concluded on page 130)

Equipment for the Collection of Fly Ash, Dust, Soot, and Smoke from the Flue-fed Incinerator

W. L. Gabbert
American Air Filter Company, Inc.
Louisville, Kentucky

In the fall of 1951, the New York City Housing Authority initiated studies of air cleaning equipment that would eliminate fly ash and smoke from apartment house incinerators. A test set-up was made available at the Dyckman Street project where each building consists of 150 tenement units, each fourteen stories high. The incinerators at this project are all the same size, each being designed to handle 50 pounds of refuse per day per dwelling unit or 7500 pounds for each fourteen story building. All are flue-fed units. Fig. 1 shows a typical unit of the type used by the New York Housing Authority.

Admiral William S. Maxwell, Deputy Commissioner of the Department of Air Pollution, New York City, has reported that the New York Department of Sanitation estimates there are 10,000 incinerators in use in that city, serving 13% of the population. He also stated that by 1970 incinerators will serve 23% of the city population indicating the increasing degree to which domestic incinerators will contribute to air pollution. In his report, Admiral Maxwell also presented data from the Sanitation Department that the average rubbish output per day is 2.33 lb. per person and that 0.52 lb. remain after burning in the incinerator to be carried away by the Sanitation Department. This represents a reduction in annual pickup workload by the Department of Sanitation of some 310,000 tons per year, and by 1970 an estimated reduction of 620,000 tons per year. Eliminating the use of incinerators is definitely impractical since it would increase the load to be removed by municipal Sanitation Departments and would increase the cost to cities and taxpayers. In view of these facts, the domestic incinerator appears to be here to stay and it will increase in number as time goes on. The main deficiencies of these incinerators are due to design, the character of the refuse used as fuel, and the operating procedure. According to Admiral Maxwell, incinerators pollute the air by producing:

1. Dust, Soot and Fly Ash
2. Smoke
3. Odors

Full scale tests at the Dyckman Street project demonstrated complete elimination of the dust, soot, fly ash, and smoke from the incinerator stack gas. According to Admiral Maxwell, the odors are not too obnoxious unless the buildings are very close and are of different heights. While no claim for odor control can be made for the air cleaning equipment used, it was apparent that odors were reduced considerably by passing flue gases through a Type W ROTO-CLONE (a wet scrubber).

Domestic refuse from the average American city formerly consisted of approximately 65% garbage and 35% rubbish by weight, the total having about 50% moisture content. But today, changes in modes of living have created new problems on flue-fed incinerators. So much food is now packed in paper containers, such as milk, frozen foods, etc., that the feed to the incinerators has changed to approximately 50% garbage and 50% rubbish. The higher percentage of paper creates hotter fires which in turn increases stack draft, thus throwing out more fly ash.

It was easy to measure the gas volume from the incinerator stack during normal operation and from that data, size the induced draft fan and air cleaning equipment required. The use of induced draft on the incinerator stack, however, did not eliminate the problem of pressure in the flue which occurs when the incinerator is cleaned—a 30 minute period during which maintenance personnel remove cans and other incombustibles and clean the grates. During this cleaning period, temperatures in the flue and gas volumes released increase extensively due to the open incinerator doors. This operation, if done during the burning cycle, causes a positive pressure in the flue, resulting in blow back of gases and smoke at the charging doors. It appears impractical to prevent this occurrence even when induced draft equipment is provided, as the added air movement simply increases the combustion rate and in turn increases the gas volume that must be handled.

With the installation of air cleaning equipment with its controlled induced draft unit, it still appears necessary either to clean the incinerator after the day's burning has been completed, or to install locks or signs on the chutes during the cleaning period to prevent feed to the incinerator during that period.

Collection Equipment

Striving for the ultimate in fly ash removal, a proposal was made to the housing authorities in February, 1952, for an installation of a series of collectors. This installation was to be made on the roof for two reasons: first, to pass all of the contaminated gases through the collector units and to try to maintain a negative pressure in the flue; and, secondly, to get the benefit of leakage around the chutes for cooling the gases before they reach the collector units. The first installation consisted of a fabric collector, backed up by a highly efficient mechanical-type filter and then a commercial, ventilation-type electrostatic unit as illustrated in Figs. 2, 3, and 4.

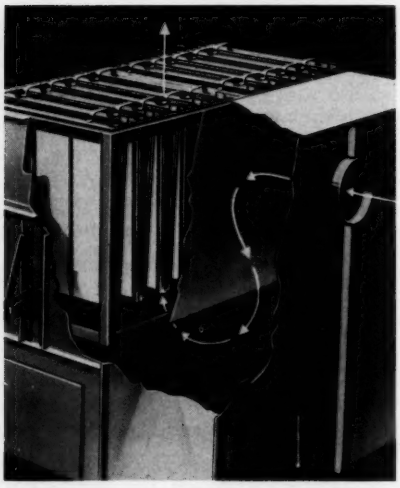


Fig. 2. AIRMAT Dustbox—The Fabric Arrester with glass cloth filter media used for collection of dust, fly ash, and soot.

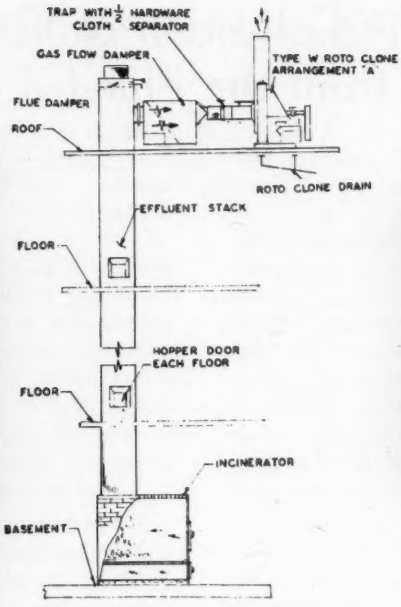
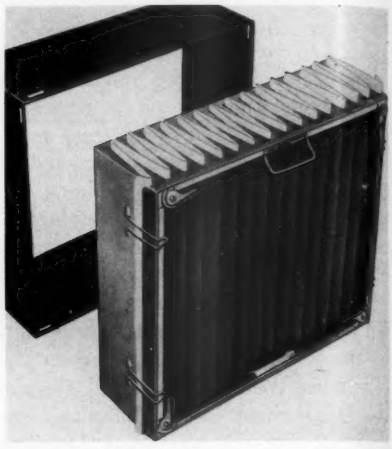


Fig. 1. Dust control for flue fed incinerator.

Fig. 3. PL Type Air Filter—Used with high efficiency glass fiiber filter media as intermediate collector for smoke removal.



The equipment used was commercially available at reasonable prices for such a job. The fabric collector, installed to collect fly ash, dust, and soot, was equipped at first with orlon envelopes, but before tests were begun, sparks and lighted newspapers were pulled into the equipment, destroying the fabric. The orlon envelopes were replaced with glass woven fabric and a trap was installed in the line to prevent a recurrence. The secondary filter was installed to remove as much of the fine smoke particles as possible that escaped the fabric collector and to reduce the concentration of contaminants in the gas passing into the electrostatic unit.

Actual tests were begun in May 1952 and the equipment operated successfully until October 1952. During this time many startling observations were made.

The biggest problem in reduction of visible discharge was a wide variation in temperature. The commercial electrostatic unit is not designed to operate at maximum efficiency at temperatures exceeding 200°-250°F. Consequently, there were periods of operation when visual effectiveness of the equipment was reduced and a slight smoke discharge was observed from the flue. The incinerators were operated from 7:00 a.m. to 7:00 p.m. and during this period the temperatures at the foot of the flue were recorded from 300° to 1150°F., the peak being reached during the one-half hour period when the operator removed the unburned debris from the grate, and varying with the cleanout time. Except during cleaning, a lower peak in the range of 500°F. was observed around 9:00 a.m. and 2:00 p.m. when the incinerator was fed its largest load. With the installation of an exhauster on the system, creating a constant induced draft over the gratings, the refuse burned more evenly and produced a more constant temperature. At times, however, the temperature still exceeded 200°F. through the electrostatic filter. The temperatures at the top of the flue going into the collector unit during this operation varied from 100° to 250°F. except during the cleaning period as shown in Figure 5, which also indicates temperatures during a normal day's cycle.

Testing

Extensive tests were conducted to determine the effectiveness of the equipment from a visual standpoint. The testing equipment consisted of air sampling tubes, one

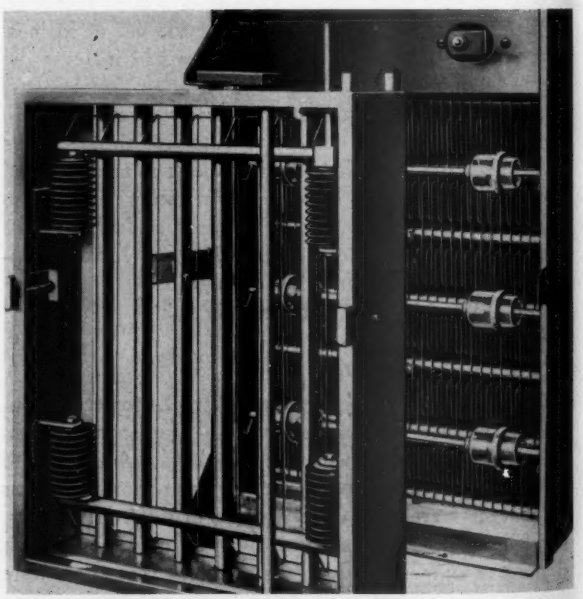


Fig. 4. ELECTRO-CELL—Low voltage electrostatic precipitator for final cleaning of flue gases to remove visible smoke.

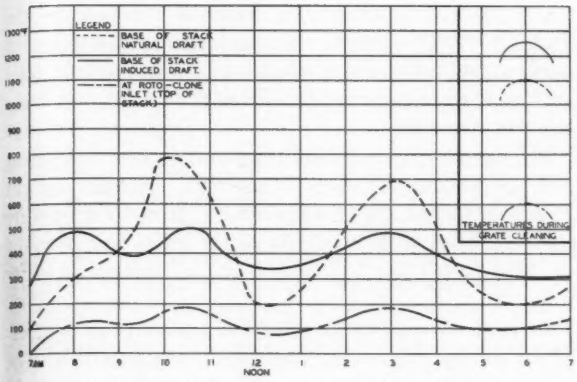


Fig. 5. Comparative temperature data—flue fed incinerator.

located before and the other after the collecting units. Known volumes of air were drawn through each tube. From the comparative discoloration of the targets the operating efficiency in all tests proved to be higher than 90%. This particular test, developed by the U. S. Bureau of Standards, is known as their "Discoloration Method of Testing" and is used exclusively in testing low voltage electrostatic precipitators. Actually, on a weight basis, the efficiencies greatly exceeded 99% by weight. Figures 6, 7, and 8, show a few of the actual test targets. The targets graphically demonstrate the effect of temperature differences, the higher the temperature the dirtier the target in the flue and also the corresponding target after the collector.

Fig. 9 shows the fly ash removed from the hopper of the fabric arrester after 36 hr. of operation, about ¾ bu. It was composed mostly of ash from rubbish and partly burned paper particles. There was evidence of hair and carpet sweepings that apparently had been fed into the incinerator without bagging or wrapping.

The secondary filter medium is shown in Fig. 11 and 12. This is a glass material, nonhygroscopic and noncombustible, and it was used to reduce the load on the electrostatic filter. It actually has an efficiency by itself of better than 60% by the Bureau of Standards Discoloration Test. Fig. 11 and 12 show how the gas contaminates permeated the medium after ten weeks of operation. Its use in place of the fabric arrester as the primary collector was prevented by plugging with fly ash, dust and soot.

Wintertime Operation

The unit continued to operate until late October. One morning the temperature dropped to 25°F. and revealed problems of wintertime operation. In removing the glass fabric envelopes, it was found that grease had solidified, completely plugging the gas passages. If the unit had not been shut down during the night, the warm gases would have prevented this occurrence. However, after the glass envelope pads were laundered, they were reinstalled and the equipment returned to operation. Plugging recurred in two weeks, sufficient proof that if such equipment were used in a colder climate, either warm gases would have to be passed through the equipment 24 hr. a day during cold

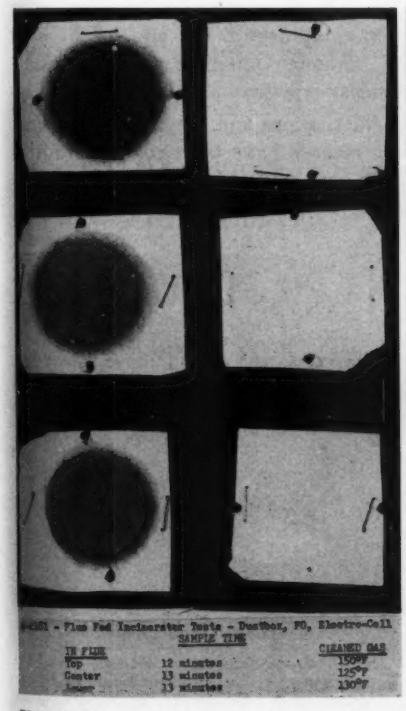


Fig. 6. Flue fed incinerator test specimen.

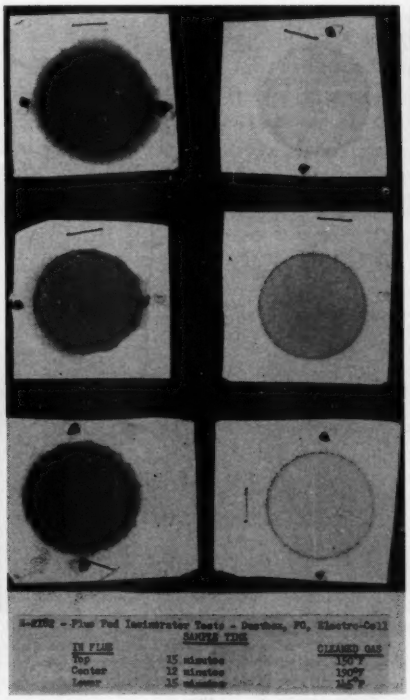


Fig. 7. Flue fed incinerator test specimen.

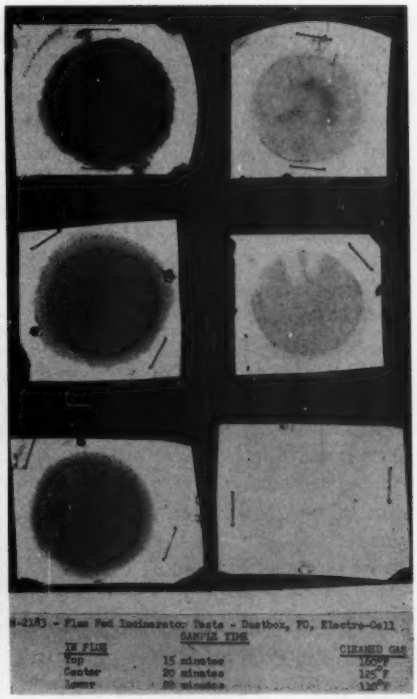


Fig. 8. Flue fed incinerator test specimen.

Fig. 9. An illustration of the fly ash, dust, and soot that can be removed from flue fed incinerator stacks.

weather, or the equipment would have to be mounted in a heated area or penthouse. Either procedure would be too expensive, so wet collection equipment was installed in place of the fabric bag arrester and its performance was studied.

A small trap (to remove large pieces of paper) and a wet collector (a Type W ROTO-CLONE, Fig. 10) were installed. The latter is both a prime mover and a centrifugal, high efficiency, wet-type dust precipitator. For the smoke removal phase, the previously used filter medium and electrostatic unit were employed. No freezing problem was encountered as the 1.5 gpm. of water used drains immediately from the ROTO-CLONE. This particular type of wet collector will not freeze during extremely cold weather. It can, therefore, be mounted on the roof if adequate precautions are taken for draining exposed water supply lines. The ROTO-CLONE with the single spray used 1.5 gal. of water per minute. Standard materials were used in the Type W ROTO-CLONE. Some question was brought up as to corrosion but after operating for more than one year, there is no evidence of corrosion in the Type W ROTO-CLONE of standard construction. All parts are still in excellent condition. The incinerator gases are cooled to approximately 100°F. before they enter the electrostatic unit.

The same tests were conducted on this new equipment and performance between 90 and 93% efficiency by the Bureau of Standards Discoloration Test was consistently reported. Over 90% by weight of the solids was removed by the wet collector. The equipment has now operated for over a year.

Records covering the service and maintenance requirements during a full year's operation are available. The electrostatic precipitator required cleaning every 8 to 10 weeks. The secondary filter required medium replacement every 12 weeks, while the ROTO-CLONE itself has not required any maintenance except lubrication of the bearings and the motor.

Conclusions

(1) Air cleaning equipment commercially available will remove with high efficiency the coarser solids causing public nuisance complaints and consisting of fly ash, dust, and soot.

(2) The addition of low voltage, air filter type of electrostatic precipitators with precleaning filters will remove practically all visible smoke, where the additional equipment and maintenance costs are justified.

(3) Condensation of grease vapors during cold operation must be considered in colder climates. Wet type collection equipment is not affected by such condensation, although plugging of fabric media is indicated unless expensive precautions are taken.

(4) Temperature fluctuations and ranges, dust loadings and operating records have been compiled during a two year test on a typical fourteen floor flue-fed incinerator.

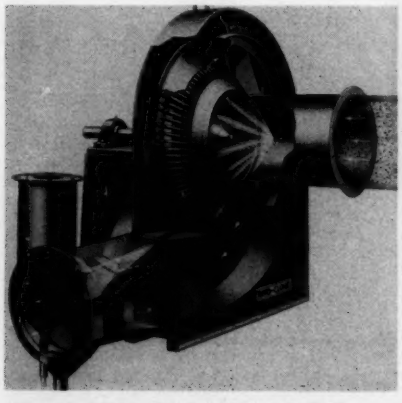


Fig. 10. TYPE W ROTO-CLONE—A combined centrifugal exhaust and high efficiency wet dust collector for collection of fly ash, dust, and soot.

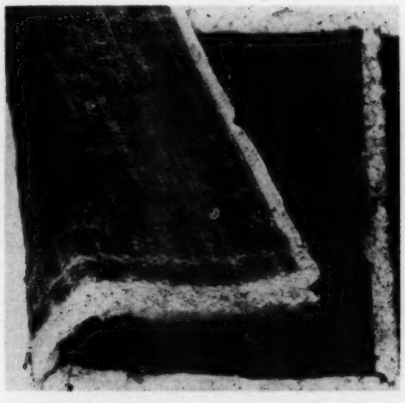


Fig. 11. The intermediate filter removes considerable smoke and reduces load on the electrostatic final cleaner.

Fig. 12. Penetration and removal ability of the intermediate filter media is indicated by the discoloration throughout the entire media thickness.

Acknowledgement

We appreciate the cooperation given us by the New York Housing Authority, especially by Mr. Albert Doud and Mr. Douglas McKay for their efforts and assistance during this study.

DISCUSSIONS OF PAPER BY W. L. GABBERT ENTITLED "EQUIPMENT FOR THE COLLECTION OF FLY ASH, DUST, SOOT AND SMOKE FROM THE FLUE-FED INCINERATOR"

This paper describes the results of the application of several types of conventional gas cleaning equipment to incinerator flue gases. While the test results indicate that the equipment is doing an acceptable job from the standpoint of removal of smoke and solids from the gases, no reference is made to the reduction of odors. In the operation of chute-fed incinerators, odors are a definite problem and the elimination of odors is of equal or more importance than the removal of solids.

Several references were made to the weight efficiency of the various collectors. It would be interesting to know how the weight efficiency was determined.

It appears that the equipment described is quite complex and that the operation and maintenance would require rather skilled personnel. It is doubtful that the operators of incinerators in the average small individually owned apartment building would be qualified to operate and maintain this type of equipment.

Cost is also a factor. A statement from the author concerning cost per apartment or per bedroom for apartment building application would be informative.

In searching for performance data on the air pollution potential from apartment building chute-fed incinerators, one encounters much difficulty uncovering factual information. This paper is helpful as it describes work of a technical nature, work that has been done on flue gas cleaning; and it will interest those confronted with this problem.

CHARLES W. GRUBER,
Chief Smoke Inspector
Cincinnati, O.

Reply to C. W. Gruber

During the tests conducted for the collection of fly ash, dust, soot and smoke from flue-fed incinerators no effort was made to determine the amount of odor reduction achieved. It is known, however, that odors are reduced by passing contaminated gases through wet scrubbers and electrostatic precipitators. Some odors from an incinerator are carried into the atmosphere on dust particles, the particles varying in size from .02 to .05 μ or larger. The balance of the odors undoubtedly are carried into the atmosphere in the gaseous state. The odor carried on larger particles does not escape the wet scrubber and electrostatic precipitator. Further reduction of odor was effected by the fact that the exhauster, acting as an induced draft fan, created a more even burning temperature and did not permit the refuse to lie smoldering during the low temperature peaks.

Determining efficiencies by the weight method is common practice in most dust control installations. The equipment used is relatively simple, consisting of a small compressor capable of handling 5-10 cfm. and 2 sampling tubes, so that simultaneous tests can be taken before and after the collector. The sampling tubes contain filter cartridges made of spun glass, a highly efficient material. The filters, or targets, are dried and weighed before the tests are started. They are placed in the sampling tube and a known quantity of air is pulled through the filters. The test period varies from 1 to 3 hr. depending on the dust concentration. The targets are then removed from the tubes and again dried and weighed. From these data, dust concentrations and efficiencies can be determined.

During the test period the maintenance requirement on this equipment was relatively simple. Although the wet scrubber (which is a prime-mover, or exhaust fan) did not need attention, it would require periodic oiling of the bearings and the motor—certainly not a skilled job. The secondary filter, composed of fiber glass, had to be changed after twelve weeks' operation. Replacement of this medium is relatively simple and is done every day on other installations by unskilled workmen. The electrostatic filter was cleaned on an average, during the 6 month period, every 8 or 9 weeks—a simple operation. However, service on the power pack would require an electrician.

The combination of equipment in a package unit sells for around $4,000.00 and the installation cost is estimated at $1,000.00. So, on a building housing 150 tenants, the cost per apartment is around $33.00. The cost for operating the unit (other than maintenance) would involve only the cost of electricity and water—water consumption at less than 1.5 gpm. and power consumption at less than 3 kw.

We wish to thank the author of this paper for a very interesting discourse on collection equipment for incinerators.

In regard to the testing procedure, to what extent does the comparative discoloration test indicate removal of odor? Naturally, with 90% reduction in discoloration, the collection equipment did improve the situation.

Were any definite tests made regarding the actual emission rate before and after the collectors, based on particulate matter?

As this equipment collected only ¾ bu. of material in 36 hours, can such elaborate equipment be justified economically?

Would it be advisable to make a recommendation as to the type of collector that should be installed on incinerators of this type?

Must this equipment be kept in operation continuously, or is it operated only under manual control?

Has any evaluation been made with the comparative discoloration method on incinerators using a secondary combustion chamber and settling chamber to control the problem, rather than a collector?

HOWARD J. SCOTT,
Division of Air Pollution Control
Cleveland, O.

Reply to H. J. Scott

We believe that we have answered in part Mr. Scott's discussion on testing procedure and odor removal in our reply to Mr. Gruber.

In addition, however, these tests gave us a final concentration of particle emission from the collecting unit, ranging from 0.35 to 0.45 gr./1000 cu. ft. of gas. The ¾ bu. of material that was collected in the 36 hr. period represents about 14 gr./1000 cu. ft. of gas.

All of the equipment on these tests was operated continuously during the burning period. The equipment was started up before igniting the fire and was not shut down until the fire was wetted down. There was no push-button starter control, but such control could be provided. To the best of my knowledge there has been no evaluation of the comparative discoloration test method on incinerators using secondary combustion and settling chambers to control the air pollution problem.

Reply to Richard Goder

(See comment by R. Goder, page 115 of this issue of Air Repair.)

The installation of the Type W ROTO-CLONE in a series of collectors has reduced the necessity of extending the chimney because of loss of flue draft. In fact, the ROTO-CLONE has improved the flue draft by inducing more air, causing a more even burning of the refuse. At all times in the flue a very high, satisfactory negative pressure was maintained which prevented any possibility of blow-outs. We did find, however, that the cleaning of the grates had to be controlled in order not to break the negative pressure. It is my opinion that no equipment could handle the volume of gases during the cleaning period to prevent blow-out from the chute doors, and that instructions should be provided with all flue-fed incinerators that grates should be cleaned only during the period when the incinerator had been wetted down. We have had very little experience with class 3 incinerators utilizing the boiler chimney. However, it is our impression that such incinerators would not be practical in most of the New York housing developments because of the cost of maintenance and labor in collecting and hauling the refuse to a central burning point. Most of the new housing developments in New York occupy several square city blocks, necessitating long hauls with large loads. I agree with Mr. Goder that utilizing the boiler chimney and burning under the supervision of an engineer would greatly reduce the soot, fly ash and odors that are presently being emitted from flue fed incinerators.

Reply to H. W. Lincoln

(See comments by Mr. Lincoln, page 116 of this issue of Air Repair.)

Some of the questions brought up by Mr. H. W. Lincoln regarding particle sizes, efficiencies and methods of testing have been answered in other replies.

I do agree that some study should be given the matter of testing flue gas emission wherein the performance of the incinerator, or the collector on the incinerator, is based on true solids concentration rather than CO_2 deficiency.

Atlantic Air Pollution Control Program

W. B. Hart
The Atlantic Refining Company

Not so many years ago the atmospheric pollution abatement program of The Atlantic Refining Company at Philadelphia, Pennsylvania, consisted of a real shrill air whistle. A blast on that whistle set in motion the only procedure involved. Everybody "took off" with the greatest possible haste for other parts up-wind. When the gas cloud had been dissipated, or moved away by the wind, they came back and went on with the work as usual. You can readily see that this was a situation to fit the old expression—"Every man for himself, etc."

The above conditions existed about thirty or forty years ago. The escape of sulfur dioxide presented a real hazard to human life and, of course, seriously disrupted the acid treatment procedure. This procedure was a part of the refining of lubricating oils, waxes and similar products.

Various attempts were made to prevent the gases escaping from the agitators from reaching the air. Among these, and probably the most successful, was the caustic washing of the gases. However, not only was this a very expensive method, but also salts were formed in the circulating lines causing no end of trouble in keeping the washing system open and in operation. Further, we simply were transferring the air pollution problem over to the waste water system and creating a waste water pollution problem in the Schuylkill River on which the refinery is located.

Another problem was presented by the units in which spent sulfuric acid, separated from sludges resulting from acid treatment of petroleum products, was concentrated. The concentrated acid could then be brought to strength for re-use by fortification with a calculated amount of strong acid. The concentrating units presented a very serious problem which simply had to be corrected. Since the cost of operation of these units was gradually creeping up to an undesirable level, due to continual trouble with the ells leading the heated air into the body of acid in the unit, and also due to trouble with the Cottrell precipitators, we began to look about for a type of concentrator which would not make fumes and would bring about concentration at lower temperatures. The higher temperature required by the existing concentrators caused decomposition of the acid by the carbonaceous material it carried. This was accompanied by the release of much sulfur dioxide which the Cottrell precipitators did not stop from getting into the air. The problem was corrected by doing away with the under-surface type of concentrator and installing a two-stage vacuum type. This unit made no fumes and operated at a relatively low temperature. It was the first real successful pollution abatement accomplishment.

But residual sludges from the separation of acid sludges still had to be destroyed and when these residual sludges were burned in our waste burning boiler house, various mercaptides, disulfides, etc., went up the stack into the air. These compounds came almost entirely from sludges derived from the acid treating of light oils and naphthas. Also, the demand for acid of higher strength than could be produced in the vacuum concentrator practically drove us into installing a sludge conversion unit, the final phase of which is a normal contact sulfuric acid unit. It has eliminated the odors from the boiler house stack while giving us a much lesser problem, i.e., the smoke from the stacks of the sludge decomposing units. This is the problem on which we are now working. But we have ample evidence that a real improvement has been brought about.

As a refinery, we have, of course, not only stills of various types, but also boiler houses, and we consume a lot of fuel every day. No coal is burned—only fuel oil and gas—yet from time to time we have smoke. Smoke and sulfur dioxide constitute our greatest problems, but we are moving rapidly toward solutions that will abate pollution to a satisfactory degree by both these pollutants. Actually, the emission of smoke presents only a relatively minor problem.

The need for solving the problems which have been briefly described was recognized early and thought was being given even before the Second World War to the form the solution might take. This consideration was interrupted by the war and all attention was given to the wartime effort. The subject was not given serious thought again until about 1947 when Philadelphia began to discuss an atmospheric pollution abatement ordinance. Such an ordinance was enacted in 1948 and another in 1954.

About 1952, Management requested that a well-organized program be established and followed so that we could be sure of what atmospheric pollution required attention, where it originated and how serious it was. We were given sufficient funds to meet the requirements of program development. We also had the advantage of experience with a similar activity in water pollution abatement.

An Air Pollution Abatement Committee was organized composed of representatives from the following divisions and departments providing representation of the pollution sources and investigational personnel:

The Refinery Division
The Lubricating Oils Division
The Chemicals Division
The Steam Division

(Continued on page 169)

Dust and Fumes from Gray Iron Cupolas—How They Are Controlled in Los Angeles County

HOYT R. CRABAUGH, ANDREW H. ROSE, JR., AND ROBERT L. CHASS
Los Angeles County Air Pollution Control District

The fundamental engineering problem of the control of air pollutants resolves itself into a need for a means of reducing the concentration of solid, liquid, and gaseous contaminants existing in the atmosphere. The obvious engineering solution to this is a reduction to a minimum, commensurate with the local air pollution problem of all air contaminants discharged at known sources. The concept of reduction at the source must be considered as a basic engineering premise in the solution of air pollution problems. The engineering means to accomplish this are three-fold:

1. The installation of control equipment on a given process or equipment to remove the pollutants from the gas stream prior to its discharge to the atmosphere.
2. A process change to minimize pollutants from the process gas discharge.
3. A modification or redesign of equipment employed in a given process to minimize pollutants in the gases discharged to the atmosphere.

The first of these engineering approaches, that of the installation of control equipment, has been the one most widely applied to minimize the discharge of air contaminants to the atmosphere.

In the engineering evaluation necessary for the determination of proper types and designs of control equipment, the following four factors must be considered:

1. The physical and chemical characteristics of the pollutant involved.
2. The characteristics of the gaseous medium conveying the pollutants.
3. The physical and operational limitations of the types of control equipment contemplated.
4. The efficiency required for the control equipment.

The first two factors given above—the characteristics of the pollutant and the characteristics of the gaseous conveying medium—are fundamentally a function of the process equipment under consideration, in this case a cupola producing gray iron. The data in Table I are

TABLE I

DUST AND FUME DISCHARGE FROM GRAY IRON CUPOLAS

Test Number	1	2	3	4	5	6	7	8	9	10
CUPOLA DATA										
Inside Dia., Inches	26	30	30	37	48	48	48	54	60	63
Tuyere Air, scfm.	1000	1400	1260	1950	4100	4050	3500	4500	4500	7500
Iron:Coke Ratio	8.33/1	10.8/1	8.55/1	6.66/1	9.8/1	9.16/1	8.1/1	6.4/1	9.16/1	10.1/1
Process Wt., lbs./hr.	4080	5856	8120	8380	17160	22500	9720	15730	18800	39100
STACK GAS DATA										
Volume—scfm.	3000	4200	4020	5520	14160	11400	8180	17700	21000	30500
Temperature—°F.	396	990	660	1400	463	300	1410	1046	445	213
CO_2—%				12.3			11.1			2.8
DUST AND FUME DATA										
Concentration—gr./scf.	1.07	1.45	1.02	1.32	0.74	1.81	1.09	1.15	1.44	0.413
Dust Emissions—lbs./hr.	27.6	52.4	35.7	62.4	89.8	177	76.3	174	260	108
Particle Size—Wt. %										
0 - 5 μ				17.2			18.1			23.6
5 - 10 μ				8.5			6.8			4.5
10 - 20 μ				10.1			12.8			4.8
20 - 44 μ				17.3			32.9			9.5
> 44 μ				46.9			29.3			57.9
Proximate Analysis										
% Fixed Carbon				3.04	19.2			11.9		
% Volatile Material				6.70	6.6			6.8		
% Ash				90.26	74.2			81.3		

intended to indicate certain salient items relative to the characteristics of the dusts and fumes discharged from gray iron cupolas. First, it should be noted that the pollutants discharged from a gray iron cupola are predominantly solids since only 6.6 to 6.8% by weight are lost by volatilization at high temperatures. Further, the particle size breakdown on a weight basis indicates that 17 to 23% of the particles are in the 0-5 micron range and from 4.5 to 8.5% are in the 5-10 μ range. Thus, approximately 25% of the total weight discharged to the atmosphere is in the particle size range of 0-10 μ. Particle densities, although not presented in the table, range from specific gravities of 2.5 to 3.5. Since the particle sizes given were determined by sedimentation methods, there are distinct indications that the actual particle sizes are somewhat smaller than those presented.

Further reference to Table I, which actually gives data from only a few of the tests conducted by the Los Angeles County Air Pollution Control District, shows that the solids discharged from gray iron cupolas vary in concentration from 0.413 gr./scf. (for a hot blast cupola) to 1.81 gr./scf. for a standard cupola. Expressed in terms of pounds discharged per ton of material processed (coke, iron, fluxes and alloying briquettes), this shows a loss of 5.9 lbs./ton of material for the hot blast cupola and a range of 8.8 to 27.7 lbs./ton for a standard cupola. Based on the average of all tests conducted, the average discharge of dusts and fumes from a gray iron cupola is 14.8 lbs./ton of material charged.

Chemical analyses of the inorganic portions of the dusts and fumes discharged, although not presented in the table, show silicon, iron, lead, zinc and calcium compounds present as major constituents with trace percentages of aluminum, manganese, magnesium, chromium, potassium, titanium, sodium, tin, copper, nickel, barium, strontium, zirconium, antimony, vanadium, bismuth and cobalt compounds. Silicon and iron compounds usually amount to about 60% of the total weight of the metallic compounds discharged.

The characteristics of the gaseous medium conveying the air contaminants from gray iron cupolas are also shown in Table I. Of major importance from a design standpoint is the temperature of the gas stream. While the table shows variations of from 200°F. to 1400°F., it should be noted that these temperatures were measured with cold air dilution ratios at the charging door of 2.3-4.7:1. With reduced dilution ratios to allow for the installation of properly designed equipment at a lower initial cost, cupola gas discharge temperatures necessarily jump to the range of 1500°F. to 2200°F. It should be noted that the gaseous discharge from cupolas is acidic when cooled and collected in the presence of moisture, due principally to the presence of sulfur compounds from the coke consumed.

The third and fourth major items, those of the physical and operational limitations and the efficiencies of control equipment contemplated, must be given equal consideration in any engineering evaluation. As previously presented, the particle size distribution, the particle density and the concentration of pollutants in cupola discharges obviously dictate the use of relatively high efficiency control equipment. Table II shows efficiencies obtained on pilot plant tests of standard, relatively well known control equipment. It is noteworthy that a high efficiency cyclone and a standard dynamic water scrubber show collection efficiencies of 22.5% and 38.2% respectively, far below that required for effective control. Intermediate efficiencies of plus 70% are shown for a venturi type scrubber and an impingement scrubber. The baghouse and electrical precipitator tests show efficiencies around 95% and are well within the engineering requirements of the Los Angeles County Air Pollution Control District. It should be noted that the efficiencies obtained on pilot baghouse and electrical precipitator installations have been duplicated or bettered in full scale installations.

As mentioned at the beginning of this paper, other engineering means may be available to control the discharge of air contaminants from gray iron foundry operations, such as modification or redesign of the process or equipment employed. This is best exemplified in the application of the small reverberatory type iron melting furnace. Even though this type of equipment is limited in melting capacity, the dust and fume discharge compares most favorably with a controlled cupola which has a collection efficiency of 96%. Economic considerations of the small job shop, therefore, have led to extensive use of this type of iron melting equipment.

In making an engineering evaluation necessary to design an effective control installation for a gray iron cupola, the problems of temperature control and gas conditioning are of primary importance. In considering the solution of these problems, the economic factors of increased gas volume versus operating temperatures must be evaluated. This phase of the problem has been solved through the employment of two fundamental engineering principles of cooling—first, through the use of radiation and convection columns and, second, through the use of evaporative coolers. Both systems allow a reduction in temperature without excessive increases in gas volumes to be handled by the control equipment.

The first typical example employing radiation and convection cooling is that of the Alhambra Foundry, Alhambra, California (see Illustration 1). This foundry uses a standard 45 in. I.D. cupola, employing an iron-coke ratio of 8:1. The flue gas temperature discharge varies from 1875°F. to 2150°F. The high temperature discharge gases are conditioned effectively through the employment of 16 radiation and convection columns 42 in. in diameter and 42 ft. high, with an effective cooling area of 10,980 ft^2. The unique feature of this particular installation is the employment of a recirculating system, whereby approximately 50% of the gases which have passed through the

TABLE II

PILOT PLANT TESTS ON GRAY IRON CUPOLA CONTROL DEVICES AND OTHER GRAY IRON MELTING EQUIPMENT*

Equipment Tested	Inlet Gas Volume—scfm.	Outlet Gas Volume—scfm.	Inlet Dust Load—gr./scf.	Outlet Dust Load—gr./scf.	Efficiency %	Remarks
CONTROLS FOR CUPOLAS**						
1) High efficiency cyclone	330	384	1.225	0.826	22.5	
2) Dynamic water scrubber	1410	1760	1.06	0.522	38.2	Water added before control unit for cooling totalled 6 gpm.
3) Venturi type scrubber	375	432	1.17	0.291	71.3	2 gpm. water introduced for cooling gas stream, 3.5 gpm. added at Venturi throat, cyclonic scrubber operated dry.
4) Dynamic—impingement wet scrubber	605	995	0.95	0.141	75.6	Water rate in excess of 10 gpm.
5) Baghouse—one silicone treated glass wool bag 10" dia. x 10' long	52.7	52.7	1.32	0.046	96.5	Avg. temp. 372°F. Avg. filter ratio 3.22:1
6) Evaporative cooler and redwood pipe elec. precipitator	1160	1330	1.263	0.0289	97.7	Water rate to cooler 22 gpm.; to precipitator 2 gpm.
OTHER BASIC EQUIPMENT						
7) Natural gas-fired reverberatory furnace	.....	5160	.....	0.00288	96.2***	Melting rate 546 lbs./hr.; gas consumption rate 4200 cfh.; melting clean scrap and pig iron.

*In all cases, equipment was installed and operated according to the manufacturer's recommendations.
**The six control devices were tested on the same cupola.
***This is not an actual control efficiency, but a per cent reduction when compared to average cupola loss.

cooling system are recirculated back to the inlet duct of the cooling system. This effects a shock cooling of the gases at this point to a temperature of approximately 1100°F., which allows the use of relatively inexpensive mild steel ductwork rather than the more expensive types of alloy steels. Further, such recirculation does not increase the size of the final control equipment, but necessitates increased duct sizes in the radiation and convection cooler. The over-all heat transfer coefficient for this system is 1.59 Btu. per hour per square foot per degree F. and the gas discharge temperature from the cooler is 400°F.

The baghouse utilized in this system handles 13,100 ft³. at 400°F. gas temperature. It is of the tubular type having four separate compartments with 112 silicone treated glass wool bags 11 in. diameter and 180 in. long, giving a total filter area of 4,835 ft². Based on an inlet gas volume of 400°F., the filter ratio of this equipment is 2.7:1 and the pressure drop ranges from 3 to 4 in. water column. The shaking cycle employed in this equip-

CUPOLA DATA

Size, 45" I.D.
Flue Gas Vol. 7980 scfm.
Tuyere Air, 3450 scfm.
Iron:Coke Ratio, 8:1
Flue Gas Temp. 1875-2150°F.
Charging Rate, 20,200 lbs./hr.

GAS CONDITIONER DATA

Type, Radiation & Convection
Cooling Area, 10,980 ft².
Log Mean Temp. Diff., 670°F.
Heat Trans. Coef., 1.59 Btu./ft²./hr./°F.
Gas Vol. (Incl. Recirculation), 16,100 scfm.
Size, 16 Cols. 42" Dia. x 42" H.
Gas Temp. Inlet 1030°F.
Gas Temp. Outlet, 404°F.

BAGHOUSE DATA

Type, Compartmented, Tubular
Gas Volume Inlet, 13,100 cfm.
Filter Area, 4835 ft².
Filter Media, Silicone Glass
Shaking Cycle, 90 Min. (Manual by Compartment)
Collection Efficiency, 99+%
Tube Size, 11" Dia. x 180" Lg.
Gas Temp. Inlet 404°F.
Filter Ratio, 2.7:1
Pressure Drop, 3" to 4" W. C.
Initial Cost of Controls, $45,000

Illustration 1. Cupola Controlled by Radiation-Convection Coolers and Baghouse at Alhambra Foundry, Alhambra, California.

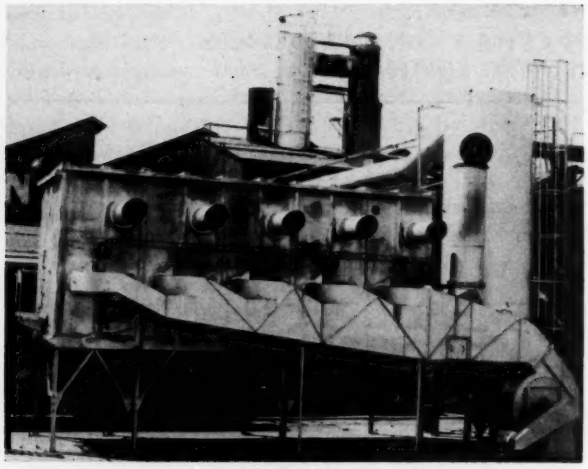


Illustration 2. Cupola Controlled by Evaporative Coolers and Baghouse at Lincoln Foundry, Vernon, California.

ment is manual, with each compartment being dampered from the gas flow during the shaking operation. Under normal operating conditions shaking is required about once every 90 minutes. The over-all efficiency of this equipment under normal operating conditions is in excess of 99%.

The second example covers the employment of a baghouse as a control unit, utilizing evaporative coolers as a means of cooling and conditioning the gases. Equipment based on these design principles is in operation at the Lincoln Foundry, Vernon, California (see Illustration 2). This company operates a 54 in. I.D. cupola, using an iron-coke ratio of 5.3:1. The cupola gas discharge is 7,400 scfm. at a gas temperature varying between 1580°F. to 1790°F. The gases are conditioned through a two-stage evaporative cooler employing 29 gallons per minute of water at 120 psi. in the primary cooler and five gallons per minute of water at 120 psi. in the secondary cooler. This results in a temperature decrease in the primary from 1600°F. to 450°F., with a further reduction in the secondary of from 425°F. to 270°F.

CUPOLA DATA

Size, 56" I.D.
Flue Gas Vol. 19,430 scfm.
Tuyere Air, 4600 scfm.
Flue Gas Temp. 1300-1600°F.
Iron:Coke Ratio, 10:1
Charging Rate, 21,500-32,500 lbs./hr.

GAS CONDITIONER DATA

Type, Evaporative Cooler
Volume, 1910 ft³.
Gas Temp. Inlet, 1200-1500°F.
Outlet Gas Vol., 33,000 cfm. @ 300°F.
Size, 9′ Dia. 44′ L.
Water Rate, 20 gpm.
Gas Temp. Outlet, 300°F.

ELECTRICAL PRECIPITATOR DATA

Type, Perforated Plate
Gas Volume Inlet, 33,000 cfm.
Electrode Length, 5450 ft.
Gas Velocity, 3.32 fps.
Outlet Dust Loss, 0.044 gr./scf.
% Moisture, Flue Gas, 14%
Collection Efficiency, 94%
Size, 13 Duct 8¾"x17′6"x18′0"
Gas Temp. Inlet, 300°F.
Rectification, Mechanical Half Wave
Retention Time, 5.42 sec.
Electrode Length/Gas Vol. (cfs.), 9.9:1
Initial Cost of Controls, $120,000

CUPOLA DATA

Size, 54" I.D.
Flue Gas Vol. 7400 scfm.
Tuyere Air, 4200 scfm.
Charging Rate, 15,800 lbs./hr.
Iron:Coke Ratio, 5.3:1
Flue Gas Temp. 1580-1790°F.

GAS CONDITIONER DATA

Type, Two Stage Evaporative Cooler
Volume Primary, 1065 ft³.
Secondary, 1010 ft³.
Gas Temp. Primary, Inlet 1600°F.
Primary Outlet, 450°F.
Outlet Gas Vol. 16,900 cfm. @ 270° F.
Size Primary, 6½′ Dia. 32′ Lg.
Secondary, 8′ Dia. 20′ Lg.
Water Rate Primary, 29 gpm.
Secondary, 5 gpm.
Gas Temp. Secondary, Inlet 425°F.
Secondary, Outlet 270°F.

BAGHOUSE DATA

Type, Compartmented, Tubular
Gas Volume Inlet, 16,900 cfm.
Filter Area, 7320 ft².
Filter Media, Preshrunk Orlon
Shaking Cycle, 15 Min. (Automatic Control by Comp'ts)
Collection Efficiency, 99+%
Tube Size, 5" Dia. x 112" Lg.
Gas Temp. Inlet, 270°F.
Filter Ratio, 2.3:1
Pressure Drop, 6" to 8" W.C.
Initial Cost of Controls, $30,000

The baghouse, designed to handle the 16,900 cfm. of gases at 270°F. discharged from the conditioner unit, is of the tubular type with five compartments. It uses 600 pre-shrunk Orlon tubes 5 in. in diameter and 112 in. long, giving a total filter area of 7,320 ft². On the basis of the baghouse inlet gas conditions as given, the filter ratio of this equipment is 2.3:1 and the pressure drop is from 6 in. to 8 in. water column. The shaking in this unit is automatic time controlled on 15 minute cycles. The gas flow is shut off automatically in the individual compartments during the shaking cycle. The overall efficiency of this equipment under normal operating conditions is in excess of 99%.

A third type of high efficiency cupola control employed in the Los Angeles area is the electrical precipitator. This is illustrated by operations at the American Brake Shoe Company, Pomona, California (see Illustration 3). The cupolas used by this company are lined to 56 in. I.D. and operate with an iron-coke ratio of 10:1. The flue gas discharge is 19,430 scfm. with a temperature varying from 1300°F. to 1600°F. The gases are conditioned through the use of an evaporative cooler operating on a water rate of 20 gpm., resulting in a temperature decrease

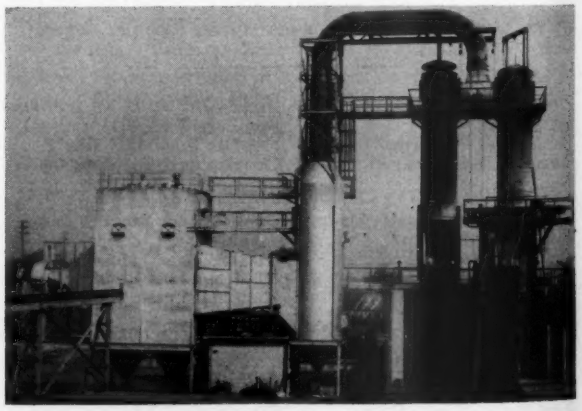


Illustration 3. Cupola Controlled by Evaporative Cooler and Electrical Precipitator at American Brake Shoe Co., Pomona, California.

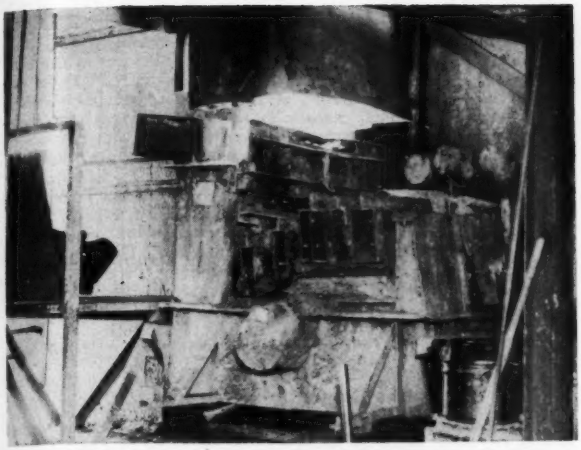


Illustration 4. Typical Example of Cupola Control by Process and Equipment Change—Gas Fired Reverberatory Furnace at Stanley Foundry, Huntington Park, California.

to 300°F. and a gas outlet volume of 33,000 cfm. Of the two cupolas, only one is used at any given time.

The precipitator controlling these cupolas is of the perforated plate collection electrode type, consisting of 13 ducts 8¾ in. wide, 17½ ft. high and 18 ft. long. The total discharge electrode length is 5,450 ft., with a gas velocity through the precipitator of 3.32 ft./sec., resulting in a retention time of 5.42 seconds. The equipment employs mechanical half-wave rectification on the electrical system and has a ratio of discharge electrode length to gas volume, expressed in cubic feet per second, of 9.9:1.

It should be noted that a unique situation exists relative to the employment of the precipitator as a control medium for gray iron cupolas in that high collection efficiencies can only be obtained through either the conditioning of the gases to a relatively low temperature containing high percentages of moisture or through maintaining the gas temperature at 600°F. or higher. The installation under discussion utilizes the former principle in that the gases are conditioned to an inlet temperature of 300°F., with a minimum moisture content of 14%, by volume.

The fourth example of equipment which is used to minimize dust and fume losses from gray iron melting operations is the gas-fired reverberatory type melting furnace. Replacement of cupolas with these relatively new furnaces is a typical example of minimizing air pollution by completely changing the basic equipment and process. One such installation is that at the Stanley Foundry, Huntington Park, California (see Illustration 4). The furnace shown is rated at 1,000 lbs. capacity and has a melting rate of 750 lbs./hr. Fuel consumption is 4,200 cfh. of natural gas. Pouring temperatures average about 2,700°F. Gas volume measured in the overhead stack is 12,270 cfm. at a temperature of 775°F. Dust and fume discharge is 0.00288 gr./scfm. When compared

REVERBERATORY FURNACE DATA

Rated Capacity, 1000 lbs.	Typical Charge, 300 lbs. Pig Iron, 500 lbs. Scrap Iron, 200 lbs. Foundry Returns, 2 lbs. Soda Ash
Fuel, Natural Gas	
Furnace Flue Gases, Calculated at 6100 cfm. @ 2850°F.	
Pouring Temp., 2700°F.	Melting Rate, 750 lbs./hr.

Fuel Rate, 4200 ft³./hr.

TEST DATA

Gas Volume at Hood, 5160 scfm.	Average Gas Temp., 775°F.
Dust Loss in grains/scf., 0.00278	Loss in lbs./hr., 0.13
Initial Cost of Equipment, $3,600	

to average cupola losses the discharge from such a reverberatory type furnace represents a reduction of more than 96%. This compares most favorably with collection efficiencies of a baghouse or an electrical precipitator.

Before a foundryman replaces his cupola with a reverberatory type furnace he must first condition himself and his employees to an entirely new method of operation. Whereas a cupola is usually in operation two to four hours a day, the reverberatory furnace must be in operation a much longer period of time to produce the same quantity of metal. Several smaller job shops in Los Angeles County have been operating these furnaces for the past two or three years. These foundrymen freely admit that this innovation has been a boon to the industry. The furnace shown in Illustration 4 has been in operation for six years.

In November 1953, the gray iron foundry control program in Los Angeles County was completed. Thirty-six baghouses, three electrical precipitators and twenty reverberatory type furnaces have been installed. These controls have resulted in a reduction of more than 95% of the contaminants formerly discharged to the atmosphere from gray iron melting operations. The means used to bring about this reduction provide no doubt of the effectiveness of the sound engineering approach that is set forth in the first pages of this treatise.

The authors are not recommending necessarily that other communities demand the same strict engineering standards nor do they advocate the use of similar air pollution control measures where the atmospheric sanitation problem is decidedly different. Each community must decide for itself the extent of control that is required to satisfy the existing conditions. It is the authors' belief, from long experience, that the control of air contaminants in Los Angeles County requires the utilization of the best engineering methods available.

DISCUSSION OF PAPER BY H. R. CRABAUGH, et al., ENTITLED "DUST AND FUMES FROM GRAY IRON CUPOLAS—HOW THEY ARE CONTROLLED IN LOS ANGELES COUNTY."

The authors are to be congratulated for their valuable contribution to our knowledge of foundry cupola fume control. Their paper is the first factual comparison of the basic types of cupola fume control installations in Los Angeles County. The foundry industry everywhere is indebted to these officials of the Los Angeles County Air Pollution Control District.

As I read this paper, it was only natural that I began to play around with the figures given on performance and costs of the three installations involving the use of dust and fume collectors in an attempt to reduce costs and gas volumes to some common basis. I came up with the comparative figures shown in the following table:

	Glass Bags Alhambra	Orlon Bags Lincoln	Precipitator Brake Shoe
Cost per scfm. tuyere	$13.04	$7.14	$26.09
Cost per inlet cfm. @ temp.	3.43	1.78	3.64
Cost per inlet cfm. @ 60°	5.72	2.50	5.35
Cost per lb./hr. charge	2.23	1.90	3.69—5.58
Inlet cfm. @ 60°	7860	11,999	22,440
Inlet cfm./lb./hr. charge	.65	1.07	1.02—1.53
Stack scfm./lb./hr. charge	.39	.47	.59— .90
Tuyere scfm./lb./hr. charge	.17	.26	.14— .21
Ratio, stack:tuyere vol.	2.3	1.8	4.2
gpm. water:tuyere scfm. x 1000		8.09 (6.3)*	4.6
Efficiency, % by wgt.	99+%	99+%	94%

*Actually evaporated

The foundry operator is interested in two phases of the cupola fume control:

(a) How much does it cost?
(b) How will it perform?

The figures speak for themselves. The cost per scfm. of tuyere air is $13.04 for the Alhambra Foundry installation which utilizes glass bags and radiation-convection cooling; $7.14 for the Lincoln Foundry installation utilizing evaporative cooling and a continuous automatic baghouse with Orlon bags; and $26.09 for the Brake Shoe installation with its evaporative gas conditioning and electrostatic precipitator. The collection efficiencies were 99+% by weight for the Alhambra and Lincoln Foundry collectors as compared to 94% for the electrostatic precipitator at American Brake Shoe.

One significant difference in the operation of the cupola at the three plants is the high ratio of stack or flue gas volume to the tuyere air volume at the American Brake Shoe Foundry. It is possible that this can be accounted for by the high rate of charging of the Brake Shoe cupolas, but I suspect that there is excess air infiltration through the charge door. I wonder if the authors can offer any explanation for this discrepancy.

One point not mentioned is the necessity of secondary combustion prior to filtration of cupola gases. In plants not practicing hot blast heat exchange, it is customary to increase the height of the cupola stack above the charge door and restrict infiltration through the charge door to permit combustion of the carbon monoxide, oil vapors, and fine, carbonaceous particles. It has been definitely established that there is a change caused by secondary combustion in character of the solid material entrained in the gases. This effect may be that of agglomeration or flocculation of the particles, but, regardless of the physical or chemical changes to the suspended particles themselves, the efficiency of filtration is greatly improved and the dangers associated with handling a toxic and inflammable gas are eliminated.

One final point which deserves mention is that of filter bag life. I know, for example, that the Orlon filter bags at Lincoln Foundry are well into their third year of operation and are still in excellent condition. I do not know either the length of service or the present condition of the fiberglas bags at Alhambra Foundry. Since bag life is an important part of the overall operating cost of the system, I hope that the authors will be able to bring us up to date on the bag life experienced in the glass bag collectors.

R. T. PRING
American Wheelabrator & Equipment Corp.

This paper is, in our opinion, excellent regarding the highest degree of dust and fume control of emissions from gray iron cupolas.

The paper fully recognizes that the Los Angeles dust and fume control standards are among the highest in the country—with a justification because of the microclimate and other similar factors.

For other parts of the country, lower standards are in existence, primarily because the cost and bulk of such stringent control equipment is high compared to other plant investment. In these other areas, "spitting distance" nuisance is probably the most common basis of control standards and resulting control practices.

The paper does *not* discuss the combustion—completion problems of excessive smoke caused by wood-crib light off, oily scrap, and ordinary or high carbon coke, when adequate after-burning provisions have not been made for the gases above the charge.

Replacement of cupolas by reverberatory furnaces is apparently limited to those operations whose one-time pour is within the holding capacity of such a furnace.

BENJAMIN LINSKY
Chief Smoke Inspector, Detroit

(Continued from page 118)

Smoke Picture of Today

any coal burning smoke. I believe there should be a great campaign put on today to try and correct some of these air pollutants.

Incinerators are another problem. Anyone living close to apartments or private homes where they have incinerators will find a greasy dirt that accumulates on window sills, front porches, doors, etc. Railroad smoke never left this greasy condition.

I believe if every city could wash their streets at night, dust could be held to a minimum, and if cities could broadcast over radio and television and newsreels about the cleaner air week program, it would reach many more individuals, which would have a bearing on cleaning up the air. Cleaner Air Week did more for the railroads than any other program I know of, because it got everyone on his toes and accomplished great results. It also helped supervision out considerably.

It is a great pleasure to visit the model city of Columbus, Ohio. Those of you who visited this city prior to the present smoke regulation program will recall the smog that hung over the city most of the day due to coal smoke. It was impossible to see the sun shine or the sky. Today it is a pleasure to see such a beautiful city, the sun shining and the air clean.

It took a great deal of work and cooperation of all concerned to bring this about.

Cincinnati reduced the smoke violations by 91 per cent during the last seven years. Much credit for this excellent record goes to Mr. T. J. Wells, Supervisor of Locomotive Operation and his assistants; also to all supervision and the City Smoke Regulation Engineer for his cooperation. In January, 1954, there were no complaints and no violations, which is a splendid record.

There are any number of cities that have done a remarkable job of cleaning up. But, as I have said before, it takes work and cooperation from all concerned to bring this about. And when I say "all concerned" I mean everyone, because we all have to breathe air.

Performance of Three Types of Fabric Dust Collectors*

CHARLES E. BILLINGS, RICHARD DENNIS AND LESLIE SILVERMAN
Harvard University
School of Public Health

Fabric dust collectors are used industrially for the separation of dusts and fumes from air and gases in many manufacturing and material handling processes. As a class, these collectors are generally greater than 99% efficient by weight on dusts ranging from 50 microns to the submicron sizes, when inlet dust loadings exceed 0.1 gr./ft.^{3}. Pressure losses across the fabric and dust layer may range from 1 to 10 in. of water, and filtration velocities may vary from 1 to 30 ft./min. Several types of fabric dust and fume collectors are available commercially. They differ in spatial arrangement and kind of fabric, method and frequency of cleaning and filtering velocity.

This paper summarizes efficiency and pressure loss data for three representative types of commercial size fabric collectors under a variety of typical operating conditions. Principal variables involved were type and concentration of aerosol, filtering velocity, method and frequency of cleaning and type of fabric.

Description and Operation of Dust Collectors Tested

Type A, Cloth Tube Collector. The cloth tube collector tested will be referred to as Type A. It is characterized by low filtering velocity (1 to 4 fpm.) and intermittent cleaning by mechanical shaking of the filter tubes while air flow is shut off. The unit consisted of two identical steel chambers, each containing thirty-two sateen weave cotton tubes, 5 in. in diameter and 6 ft. long (270 sq. ft. of cloth per chamber). In normal operation one chamber filters the dusty air while the second chamber is cleaned.

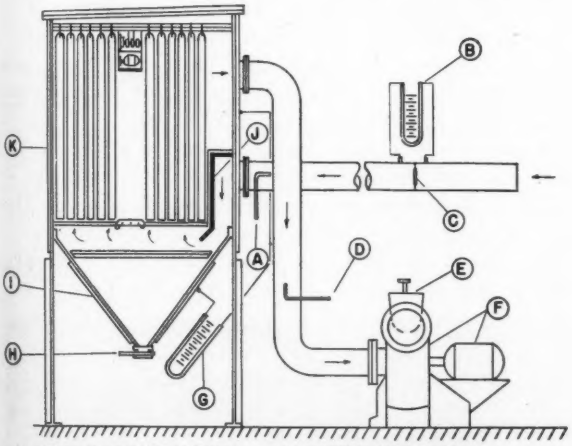


Fig. 1. Cloth Tube Collector Cleaned Intermittently by Mechanical Shaking.

Dusty air enters the bottoms of the tubes (Fig. 1) and filtration occurs on the inner surfaces. Resistance to air flow increases as the dust layer accumulates and, in practice, this results in decreased air flow. When pressure loss in one section reaches 2 to 4 in. of water an automatic damper switches air flow to the other section. The dust layer adhering to the inner surface of the tubes in the first section is removed by mechanically shaking the top of the tubes which causes the dust to fall into the hopper below. After one or two minutes the shaking is stopped and the dust is allowed to settle before returning the section to service. Operational time between cleaning cycles varies with dust loading and maximum allowable pressure loss across the collector, but usually ranges from two to eight hours.

Type B, Reverse Air-Jet Collector. The reverse air-jet collector will be referred to as Type B. It usually operates at high filtering velocities (5 to 30 fpm.) and can be cleaned continuously or periodically without shutting off the primary air flow. The test unit consisted of a cylinder of hard pressed wool felt 5 ft. high and 18 in. in diameter (20.5 sq. ft. of effective cloth area) connected to a top inlet plenum and a bottom hopper. Cleaning is provided by a hollow slotted ring made to traverse vertically the outside of the bag while in close contact with the surface. Positive pressure air (2 to 4 in. of mercury) is supplied to the cleaning ring from an auxiliary blower. Pressure loss across the wool bag and dust layer controls cleaning action by regulating the amount of ring travel (except in some applications when the ring operates continuously).

In operation, dusty air enters the top of the cylinder and dust deposits on the inner surface as air flows out through the felt (Fig. 2). Either periodically (by pressure loss controls) or continuously the cleaning ring traverses the outside of the bag, blowing a high velocity air-jet back through the felt to remove dust accumulated on the inner surface. This dust then falls into the hopper below, although some may be redeposited on the bag below the point of cleaning, since the primary air flow continues. Air flow is maintained relatively constant by the use of continuous cleaning.

*This study was made under Contract No. AT(30-1)841 between the U. S. Atomic Energy Commission and Harvard University. The opinions expressed in this paper are those of the authors and do not necessarily represent the views of the U. S. Atomic Energy Commission.

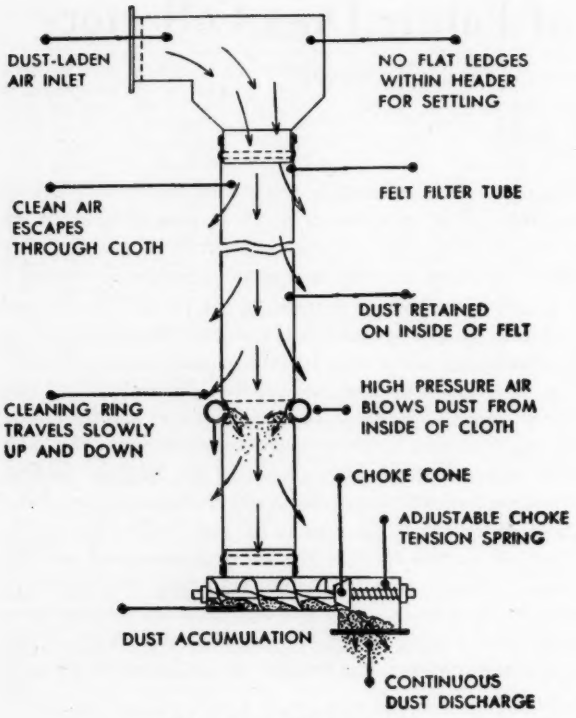

DUST-LADEN AIR INLET
NO FLAT LEDGES WITHIN HEADER FOR SETTLING
FELT FILTER TUBE
CLEAN AIR ESCAPES THROUGH CLOTH
DUST RETAINED ON INSIDE OF FELT
HIGH PRESSURE AIR BLOWS DUST FROM INSIDE OF CLOTH
CLEANING RING TRAVELS SLOWLY UP AND DOWN
CHOKE CONE
ADJUSTABLE CHOKE TENSION SPRING
DUST ACCUMULATION
CONTINUOUS DUST DISCHARGE

Fig. 2. Reverse Air Jet Collector.

Type C, Cloth Tube Collector. Type C is a cloth tube collector which provides cleaning by rapping the tubes in the presence of a current of low-velocity back-flow air. This collector operates at moderate filtering velocities (5 to 10 fpm.) and cleans automatically on a time cycle. Its principal application has been in the flour milling industry.

The collector tested had four identical compartments joined on the bottom to a common inlet plenum and hopper and on the top by means of individual dampers to a common outlet header. Each compartment contained eight sateen weave cotton tubes 6 ft. long and 8 in. in diameter (100 sq. ft. of cloth per compartment) connected to a manifold plate on the bottom and a frame at the top. Manifold and frame were rigidly connected together by rods so that the whole assembly could be lifted and dropped (about 1½ in.) for cleaning without distorting the bags. A damper at the outlet of each compartment, operated by lifting levers, shut off primary air to the fan and simultaneously vented the compartment to the room.

In operation, dusty air enters the bottom of all tubes (Fig. 3) and passes up the inside, filtration occurring at the inner surface. Cleaned air enters the outlet duct through the individual damper sections. Cleaning of each compartment is accomplished by the following steps: (1) the compartment is closed off from primary air flow and (2) vented to atmosphere by means of the damper; (3) bag frames are then lifted and dropped four times during a 0.32 minute period in conjunction with a current of back

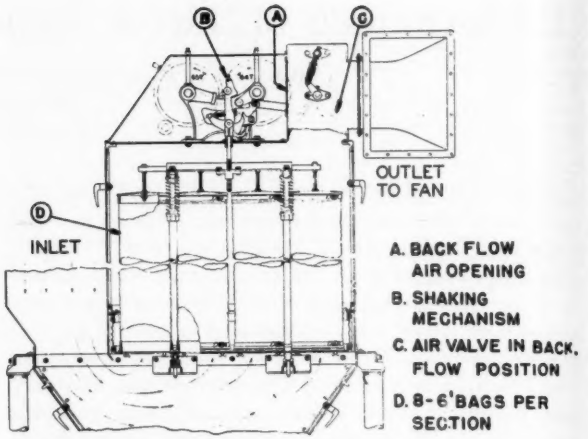


Fig. 3. Cloth Tube Collector Cleaned Periodically by Mechanical Rapping and Back Flow Air.

flow air induced by the negative pressure in the hopper and (4) shortly after the last rap (0.16 minutes) the compartment is returned to service by reversing the damper setting. This cleaning cycle then repeats in another compartment until all have been cleaned once each 5.2 minutes. In this four compartment collector, variations in air volume occurred eight times every 5.2 minutes as sections were removed and restored to service.

Test Methods and Results

A. *Atmospheric Dust*

Methods—Atmospheric dust occurs in metropolitan areas in varying concentrations according to season, weather and industrial activity. The mean particle size is about 0.5 microns by count. This dust was employed on the three collectors to evaluate the weight collection efficiency of the clean fabric. Samples of inlet and outlet dust concentrations were obtained with high volume samplers[1] using pleated paper filters (Fig. 4).

Results—The overall weight collection efficiency for each unit operating at rated filtering velocity is shown in Table I. Bags were not cleaned during these tests. The sateen weave cotton used in Type A and C collectors gave efficiencies of 74% at 3 fpm. velocity and 36% at 10 fpm. Due to a possible error in sampling of the Type C col-

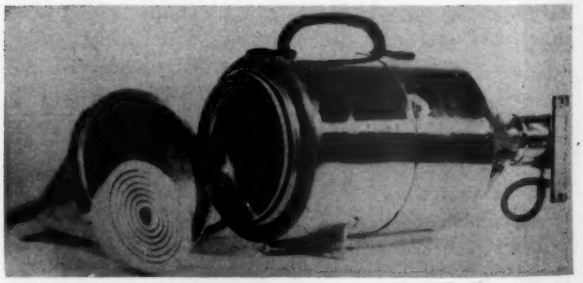


Fig. 4. High Volume Air Sampler and Pleated Paper Filter.

1. Silverman, L. and Viles, F. J., Jr., "A High Volume Air Sampling and Filter Weighing Method for Certain Aerosols," *J. Ind. Hyg. and Tox., 30: 124 (1948).*

Table I.

Weight Collection Efficiency of Three Types of Commercial Fabric Dust Collectors When Filtering Atmospheric Dust* at Rated Operating Conditions**

Collector	Filter Fabric	Filtering Velocity (fpm.)	Pressure Loss (in. of water)	Dust Concentration (gr./1000 ft.³)		Weight Collection Efficiency (%)
				Inlet	Outlet	
Type A	Cotton (sateen weave)	3	0.09	0.041	0.011	74
Type B	Wool (hard pressed felt)	25	0.81	0.035	0.010	71
Type C	Cotton (sateen weave)	10	0.29	0.045	0.029	36

* Count median diameter 0.5 microns.
** No fabric cleaning during tests.

lector, the efficiency reported (36%) is believed to be somewhat lower than would be predicted. In practice we would expect to find about 60%. The hard pressed wool felt gave an efficiency of 71% at a filtering velocity of 25 fpm. Hard pressed wool felt has been shown[2] to have an atmospheric dust efficiency greater than 80% at a filtering velocity of 8 fpm. At equal filtering velocities of 3 fpm. the wool felt would be the most efficient fabric. At rated filtering velocity, however, the clean fabric efficiency is highest in the Type A collector and lowest in Type C.

Efficiency increases from the base levels indicated above to greater than 90% after approximately 400 hours operation[3]. The use of an added layer of asbestos fibers as a filter aid has also been shown[3] to give initial weight efficiencies greater than 98% against atmospheric dust for sateen weave cotton fabric.

The clean fabric pressure losses are shown in Table I for each of the collectors operating at rated filtering velocity. Pressure loss for sateen weave cotton is 0.030 in. water/ft./min. filtering velocity. The pressure loss for wool felt is 0.031 in. water/ft./min. filtering velocity. There is little difference between the pressure characteristics of these two fabrics. In both cases air flow is in the streamline range for the usual filtering velocities employed.

B. Micronized Talc

Methods—By using comparable inlet loadings of micronized talc (Nytal 500"*, mass median diameter 2.5 microns, geometric standard deviation 1.6) it is possible to compare pressure loss and efficiency characteristics of the three dust collectors. Talc was fed onto a turntable and regulated to maintain a constant width strip[4]. This strip was then picked up and dispersed by a suction tee into the inlet duct of the collector (Fig. 5). Samples of inlet dust concentration were obtained by using a stack sampler[5] with paper extraction thimbles (Fig. 6). Outlet dust samples were obtained with high volume air samplers[1] and pleated paper filters shown previously in Fig. 4.

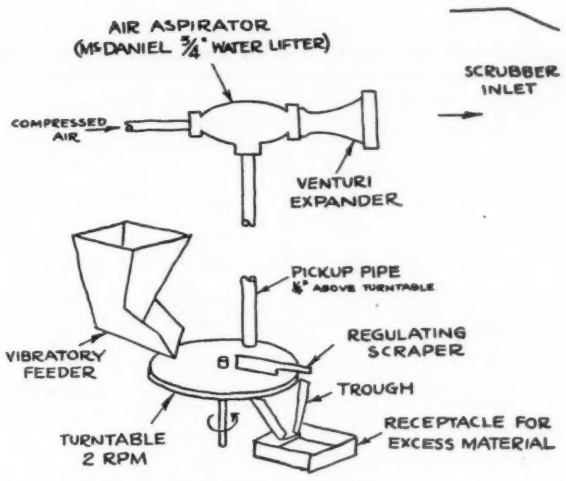


Fig. 5. Dust Generator.

Results—The pressure loss characteristics of each collector for three different inlet loadings of micronized talc are given in Table II A. As the inlet dust loading is in-

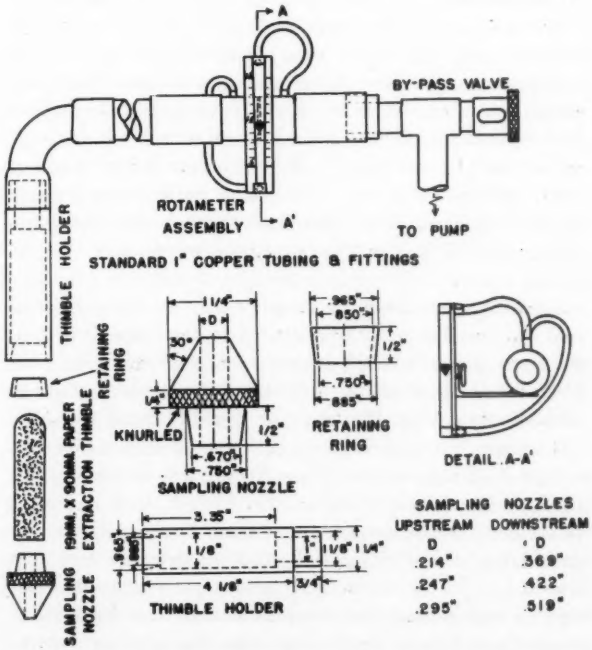


Fig. 6. Stack Gas Sampler and Attachments.

* R. T. Vanderbilt Company, New York, New York.

2. Billings, C. E., et al., "Laboratory Performance of Fabric Dust and Fume Collectors," *AEC Contract No. AT(30-1)841, USAEC, NYO 1590, Harvard University (Aug. 31, 1954).*
4. First, M. W., et al., "Performance Characteristics of Wet Collectors," *AEC Contract No. AT(30-1)841, USAEC, NYO 1587, Harvard University (April 22, 1953).*
5. Dennis, R., et al., "How Dust Collectors Perform," *Chem. Eng., 196 (Feb. 1952).*
6. Whitby, K. T., "Determination of Particle Size and Distribution—Apparatus for Flour Mill Dust," *Bull. Univ. Minn. Inst. of Tech. Expt. Sta., Bull. No. 32 (1952).*

Table II.

Operating Characteristics of Three Types of Commercial Fabric Dust and Fume Collectors When Filtering Micronized Talc* at Rated Conditions

Collector	Filtering Velocity (fpm.)	Inlet Loading (gr./ft.³)	A. Pressure Loss		B. Efficieny		
			Pressure Loss (in. of water)	Cleaning Time	Outlet Loading (gr./1000 ft.³)	Weight Penetration (%)	Weight Efficiency (%)
Type A[b]	3	0.1	0.3 to 0.7	30 min.[a]	0.012	0.012	99.988
Type B[c]	8	0.1	1.6	Continuous	0.011	0.011	99.989
Type C[d]	7	0.1	3.3	Continuous	1.4	1.4	98.6
Type A	3	1.0	0.3 to 1.5	30 min.	0.034	0.0034	99.9966
Type B	8	1.0	2.5	Continuous	0.27	0.027	99.973
Type C	7	1.0	4.7	Continuous	2.1	0.21	99.79
Type A	3	2.0	0.5 to 3.0	30 min.	0.070	0.0035	99.9965
Type B	8	2.0	2.9	Continuous	0.39	0.020	99.980
Type C	7	2.0	5.2	Continuous	.....	.....	.....

* Mass median diameter 2.5 microns, geometric standard deviation 1.6.
a. Time required for pressure loss to increase amount shown.
b. Sateen weave cotton tubes cleaned intermittently by shaking.
c. Hard pressed wool felt cylinder cleaned continuously by reverse air-jet.
d. Sateen weave cotton tubes cleaned in sections once each 5.2 minutes by rapping and back flow air.

creased from 0.1 to 1.0 gr./ft.³ the pressure loss for the Type A collector doubles in the same time interval (30 minutes). Type B and C collectors show an increase of about 50% in average pressure loss for the same change in loading. As the dust loading increases from 1.0 to 2.0 gr./ft.³ the Type A collector pressure loss again doubles, while the Type B and C units have an increase of 16 and 10%, respectively, in pressure loss. Higher dust loadings produce much larger changes in pressure loss in the Type A collector than they do in the Type B and C units.

By comparing the three collectors at *rated* filtering velocity and the same dust loading (0.1 gr./ft.³) it appears that the Type A collector has the lowest average pressure loss (0.5 in. water), the Type C has the highest (3.3 in. water), and the Type B is about halfway between these two (1.6 in. water). If the comparison is made at *equal* filtering velocities (3 ft./min.) the average pressure losses (based on streamline flow through the bed) are: Type A, 0.5 in. water; Type B, 0.6 in. water; and Type C, 1.4 in. water.

Similar comparisons of pressure loss at *rated* filtering velocity and 1.0 and 2.0 gr./ft.³ dust loadings show that the Type A unit has the lowest average pressure loss, the Type C has the highest, with the Type B about midway between these two. However, at *equal* filtering velocities the average pressure loss of the Type B unit is equal to or less than that of the Type A unit, for the same dust loading. The pressure loss in the Type C unit is always higher than the others, on either basis of comparison.

At 2.0 gr./ft.³ the Type A collector pressure loss rises from 0.5 to 3.0 in. water in 30 minutes of operation. During this time period there may be excessive or inadequate process ventilation, depending upon the pressure-volume characteristics of the blower. Normal design usually provides correct ventilation volume at the maximum pressure loss estimated for the collector, just before shaking.

The Type B and Type C collectors maintain a relatively constant pressure loss during operation, so that air volume also remains relatively constant.

The comparative efficiencies of these three collectors are reported in Table II B for similar loadings of micronized talc. As the inlet loading is increased from 0.1 to 2.0 gr./ft.³ the outlet loading increases for each collector. At an inlet dust loading of 0.1 gr./ft.³ the outlet loading of the intermittently cleaned collector (Type A) is equal to that from the continuously cleaned reverse jet collector (Type B). With higher inlet dust loadings (1.0 and 2.0 gr./ft.³) the outlet loadings of the continuously cleaned reverse jet unit (Type B) average seven times higher than those from the intermittently cleaned unit (Type A). Outlet loadings from the periodically cleaned unit (Type C) are substantially higher than those from the other two units. Within the range of the test data the efficiency of the intermittently cleaned collector (Type A) determined between cleaning cycles (i.e., without cleaning) equals or exceeds the efficiency of the reverse jet collector (Type B) determined during continuous cleaning. Lowest efficiency was associated with the periodically cleaned collector (Type C).

C. Resuspended Fly Ash

Methods—Cottrell precipitated fly ash from a local power company (mass median diameter 16 microns, geometric standard deviation > 3.0) was also used to compare pressure loss and efficiency characteristics of the Type B and Type C collectors. The Type A collector was not tested on fly ash. The same methods of generating, sampling, and analyzing previously described for micronized talc were used for testing with fly ash.

Table III.

Operating Characteristics of Two Types of Commercial Fabric Dust Collectors When Filtering Resuspended Fly Ash* at Rated Conditions

Collector	Filtering Velocity (fpm.)	Inlet Loading (gr./ft.³)	A. Pressure Loss		B. Efficieny		
			Pressure Loss (in. of water)	Cleaning Time (%)	Outlet Loading (gr./1000 ft.³)	Weight Penetration (%)	Weight Efficiency (%)
Type B[a]	10	1.0	1.3	100	0.36	0.036	99.964
Type C[b]	10	1.0	3.1	100	2.2	0.22	99.78
Type B	10	5.0	1.6	100	0.80	0.016	99.984
Type C	10	5.0	4.6	100	4.2	0.084	99.916

* Mass median diameter 16 microns, geometric standard deviation > 3.

a. Hard pressed wool felt cylinder cleaned continuously by reverse air-jet.

b. Sateen weave cotton tubes cleaned in sections once each 5.2 minutes by rapping and back flow air.

Results—Table III A shows the pressure loss characteristics of the Types B and C collectors at two comparable loadings of resuspended fly ash. The pressure loss of the Type C collector is about 2½ times higher than that of the Type B collector when operated at the same filtering velocity and equal dust loading. The increase in average pressure loss for an increase in inlet dust loading from 1.0 to 5.0 gr./ft.³ is 22% in the Type B unit and 48% in the Type C unit.

Efficiency characteristics of the two collectors are reported in Table III B. At 1.0 gr./ft.³ of fly ash the outlet loading of the Type C collector is six times higher than that of the Type B collector. At 5.0 gr./ft.³ the outlet loading of the Type C unit exceeds that of the Type B collector by a factor of five.

When filtering equal loadings of fly ash, pressure losses and outlet loadings for the Type B collector average 2½ and 5½ times lower respectively than those of the Type C collector (within the limits of the data of Table III). Efficiency is higher and pressure loss is lower in the continuously cleaned reverse jet collector (Type B).

D. Conclusions

Pressure Loss—Laboratory tests of three types of commercial fabric dust and fume collectors operating at *rated* filtering velocities and comparable inlet dust loadings show that average pressure loss is lowest for the intermittently cleaned unit (Type A), highest in the periodically cleaned unit (Type C), and intermediate in the continuously cleaned reverse jet unit (Type B).

However, at *equal* filtering velocities, pressure loss of the continuously cleaned reverse jet collector (Type B) is equal to or less than pressure loss of the intermittently cleaned collector (Type A) and substantially less than the pressure loss of the periodically cleaned collector (Type C).

Variations—Variations in operating pressure loss are greatest with the intermittently cleaned collector (Type A). At one operating condition a sixfold increase in pressure loss was observed over a thirty-minute period. This may produce changes in air flow depending upon the fan characteristics.

The periodically cleaned collector (Type C) operates at varying air flow due to the cyclical cleaning of four individual compartments; however, the actual rise in bag pressure loss is small between cleaning cycles.

Pressure loss and air flow in the reverse jet collector (Type B) are relatively constant during operation with continuous reverse jet cleaning. Pressure controlled intermittent reverse jet cleaning requires some variation in pressure loss (½ to 1 in. water) and produces variations in air flow, depending upon the fan characteristics.

Efficiency—Dust retention in fabric collectors depends upon physical properties of both fabric and accumulated dust layer. With low inlet loading and little dust on the surface, weight collection efficiencies range from 60 to 80%, as indicated by atmospheric dust tests. With higher dust loadings (greater than 0.1 gr./ft.³) the accumulated dust layer on the surface affords efficiencies greater than 99%. In woven fabrics such as sateen weave cotton used in two collectors tested (Types A and C), this dust layer "bridges" spaces between the adjacent threads and provides a high efficiency filter layer. For felted fabrics, such as the wool used in the Type B collector, some penetration occurs (which tends to reduce pore size) prior to formation of a surface layer.

With woven fabric, any removal of dust from the surface of the fabric destroys the "bridges" between fibers and reduces the collection efficiency of the fabric. Cleaning of woven fabrics is accomplished by mechanical agitation of some type, without primary air flow. When the fabric is returned to filtering service a "puff" of dust is usually visible in the outlet air, due to the breakdown of the "bridges" between the threads. Many efficiency determinations in collectors using woven cloth do not include initial loss of dust as part of the sample. If the fabric returns to 80% efficiency immediately after cleaning, and does not reach 99.99% for several minutes, samples including this initial period after cleaning may show higher overall outlet dust loadings.

Cleaning of felted fabrics by reverse air-jet removes dust from the deposited surface layer and may remove or reorient some of the dust imbedded within the pores. This

process allows some dust to escape through the fabric to the clean air side. Repeated disturbance of the dust layer resulting from continuous cleaning can be reduced considerably by employing intermittent, pressure controlled reverse jet air. With blow ring traverse time reduced to 45%[3] the outlet dust loading of micronized talc decreased from 0.012 to 0.0025 gr./1000 ft.^{3} (with inlet dust loading of 0.1 gr./ft.^{3}). Other test dusts (resuspended fly ash and vaporized silica) have shown similar reductions in outlet dust concentrations. If the initial "puff" of dust from the intermittently cleaned unit (Type A) is included as part of the overall outlet dust loading or when the reverse jet unit (Type B) is operated with intermittent pressure controlled cleaning, the efficiency of the reverse jet collector (Type B) may be comparable to that of the intermittently cleaned unit (Type A).

Efficiency of the periodically cleaned collector (Type C) is considerably lower than the efficiencies of the Type A and B units. The periodically cleaned collector (Type C) removes the "bridges" of dust between threads every five minutes, at each cleaning operation. Part of the filtering cycle following cleaning is devoted to replacing these "bridges," and until this occurs the overall collection efficiency is lowered.

Selection of one of the three types of collectors discussed above also depends upon considerations of capital investment, and maintenance and power costs during operation beyond the scope of this paper. Generally with air volumes less than 12,000 cfm., the Type A collector has the least amount of auxiliary equipment, the Type B has the most, and Type C has slightly more than the Type A. Under the same conditions, power required to operate auxiliary equipment is highest in the Type B collector, and lowest in the Type A unit.

The reverse jet collector (Type B) operates at a relatively constant pressure loss (and constant air flow) and large changes in dust loading (above 5 gr./ft.^{3}) make little difference in pressure loss[3]. Efficiency of the Type B collector may be comparable to that obtained in the Type A collector when the Type B unit is operated at moderate filtering velocities and with pressure controlled cleaning. The Type C collector operates at higher pressure loss and lower efficiency than either Type A or Type B (with comparable aerosols). However, as indicated previously, its usual application has been in the flour milling industry on large particle sizes[6].

Selection of fabrics is not necessarily limited to those discussed in this paper. For special applications, i.e., metallurgical fume collection or acid or caustic service, orlon or wool felt bags may be used in the Type A or C collectors. Woven glass bags (suitable for high temperature filtration) have been tested in the Type C unit and show satisfactory retention and pressure loss characteristics. However, no life tests have been conducted in this laboratory to determine their long range resistance to mechanical rapping or abrasion. Special resin or silicone treated wool felt bags are obtainable for use in the Type B collector to improve collection efficiency.

3. First, M. W., Silverman, L., et al., "Air Cleaning Studies, Progress Report, Feb. 1, 1951 to June 30, 1952," *AEC Contract No. AT (30-1) 841, USAEC, NYO 1586, Harvard University (Dec. 16, 1954).*

(Continued from page 108)

Ozone Formation With Hydrocarbons

be considered as a definite source of smog.

Summary

The concentrations of nitrogen dioxide and hydrocarbon at which photochemical ozone formation occurs have been determined, using 3-methylheptane as a standard hydrocarbon. N-butane, n-pentane, n-hexane, n-heptane, n-octane, n-nonane, and 1-hexene showed similar behavior. The ozone formed was determined by rubber cracking and by chemical means. No ozone formation was found with methane or ethane.

Experimental proof of the ozone generating capacity of automobile exhaust gases was obtained by irradiation of dilute exhaust gases from the cruising and accelerating phases of automobile operation. Exhaust gases from idling and deceleration phases formed ozone photochemically after addition of nitrogen dioxide. The concentrations of ozone formed, as well as the concentrations of exhaust gases used, are of the same order as those measured in the Los Angeles atmosphere. These investigations show that automobile exhaust gases are capable of forming ozone in the air and are therefore to be considered as a definite source of smog.

New Uses of Electrical Precipitation for Control of Atmospheric Pollution

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Bound Brook, N. J.

This paper is submitted to acquaint you with the more recent applications of the Cottrell precipitator to the problem of air pollution. It is always difficult to decide what phase of this problem might be most interesting to you; but, inasmuch as last year we covered the theoretical and fundamental aspects of precipitation, we thought that at this meeting you might be interested in learning about some of the newer applications of precipitators for the reduction of air pollution. Accordingly, we will devote most of our time to this aspect. In doing so, we will break the problems down into industries and concentrate attention on the steel industry, as there has been a number of new applications developed in that industry over the past few years.

We assume that everyone present is familiar with the basic operation of electrical precipitators, so that we will not take time to discuss this phase in detail. In passing, we would merely point out that a precipitator (Fig. 1) consists of a shell in which are grouped two sets of electrodes; one, plates or pipes known as collecting electrodes, and the other, wires or rods designated as discharge electrodes. These discharge electrodes are located in the center of ducts formed by the collecting electrodes in the case of the plate type precipitator, and in the center of the pipes in the case of the pipe type precipitator. In the operation, a high voltage, unidirectional difference of potential is impressed across the two sets of electrodes which ionizes the gas, imparts a charge on the particles, and precipitates them on the electrode of opposite electrical polarity. Consequently, the essential parts of an installation (Fig. 2) consist of the precipitator wherein the gas is treated and the electrical equipment for producing the high voltage unidirectional current for the operation of the precipitator.

Electrical precipitators have been used for many years to clean gases for the reduction of atmospheric pollution, for cleaning the gas for subsequent use, and for recovery of suspended material of value.

As mentioned before, we propose to devote most of the time to a discussion of the more recent applications; but a discussion pertaining to the reduction of air pollution would not be complete without mentioning this equipment in the power industry.

Therefore, we will begin this discussion by reviewing the application of electrical precipitators for the removal of fly ash from the gases coming from boilers in central power stations.

Power Industry

Electrical precipitators have been extensively applied in this industry since about 1923 for the collection of fly ash from pulverized-coal-fired boilers. In addition to the standard pulverized-coal-fired boiler, there has been developed in recent years a so-called cyclone type of boiler. While the amount of fly ash discharged into the gases from this type of boiler is less than in the normal type of pulverized-coal-fired boiler, nevertheless precipitators have

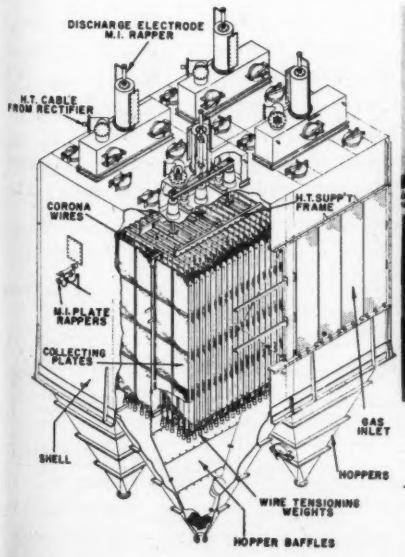

Fig. 1. Typical horizontal flow, plate type precipitator.

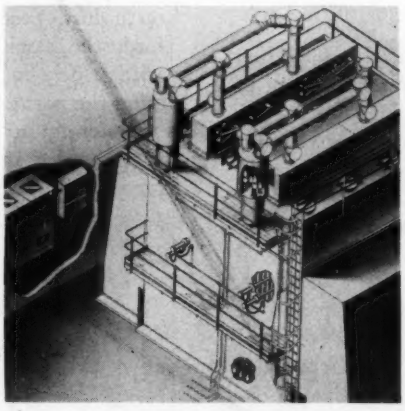

Fig. 2. Fly ash precipitator installation.

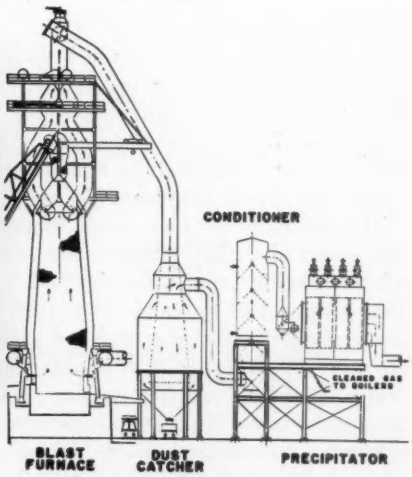

Fig. 3. Ferromanganese blast furnace gas cleaning.

been utilized on several of these installations for the collection of fly ash. The primary reason for this application is the fact that the suspended matter is extremely fine, as well as the general desire of industry to do everything possible to keep the amount of material discharged to atmosphere at a minimum. In this connection, it is most interesting to note that the requirements on efficiency of removal have been increased steadily on all applications, especially those in the power industry. The following tabulation shows the percentage of installations for fly ash removal wherein the efficiency of removal was specified as over 95% for the various periods noted.

Years	Percent of Installations Specifying 95% Removal or Better
1923 - 1939	11.3
1940 - 1944	38.8
1945 - 1949	60.5
1950 - 1953	90.0

The above tabulation indicates that last year 90% of all our installations for the removal of fly ash from pulverized-coal-fired boilers were guaranteed for 95% or more (in many cases 97 or 98%), whereas 20 to 25 years ago only 11% were installed for efficiency in excess of 95%. This shows progress in the problem of reducing atmospheric pollution from this source, and a great deal of credit should be given to this industry for recognizing the problem and endeavoring to effect as high a removal as possible consistent with economics.

The equipment usually installed for this application is a horizontal-flow, plate-type precipitator. Installations are made wherein only the precipitator is used for high removal. In other cases, the precipitator may be used in combination with mechanical-type collectors. As a matter of fact, there has been increased interest in the latter type of equipment in recent years.

Steel Industry

Ferromanganese Precipitators

A very recent application which we placed in operation in July of last year is an installation for the cleaning of ferromanganese blast furnace gas (Fig. 3).

This installation was made only after thorough pilot plant studies, ending in 1950, had indicated that we could collect this particular dust effectively in precipitators.

The gas to be treated comes from two 350 ton/day ferromanganese blast furnaces and amounts to 135,000 scfm. carrying approximately 9.0 gr./ft.^{3} of dust. This is equivalent to about 125 tons of dust/day and, of course, immediately presented a handling and disposal problem. The collected dust is very fine and packs quite easily. Therefore, effective rapping means had to be developed for removing it from both wires and plates continuously. In addition, due to the unique chemical and physical properties of this dust, special handling and processing equipment had to be installed in addition to the actual collecting equipment. The method of processing this dust was worked out by the purchaser in extensive pilot plant studies and consisted, essentially, of complete oxidation to destroy or render inert any obnoxious chemical elements or properties and pelletizing the material in order to facilitate handling and storage.

The results to date have been gratifying. While there are still some minor problems of a mechanical nature to be resolved, our work indicates that the fundamental problem of cleaning ferromanganese gases for boiler use with electrical precipitation equipment has been eminently successful. This has resulted not only in reducing atmospheric pollution but in considerable savings in the operation and generation of steam in the boiler plant. The atmosphere has been cleared of more than 100 tons/day of dust. This in itself is a very important item.

The installation consists essentially of five precipitators, each of which is preceded by a cooling and conditioning tower, and arranged to handle the gases in parallel. Consequently, the gas from the raw gas mains flows through the cooling tower, where it is cooled and conditioned to approximately 450°F. after which it passes to the precipitators. These are the standard horizontal-flow, expanded-metal-steel-plate type similar to our fly ash precipitators. Isolating gas valves were installed so units could be taken out of service for repairs. The dust has to be removed from the hoppers continuously to prevent it from packing. Dust plows were also provided for each precipitator and conditioning tower hopper to assist in moving the dust to the dust handling system.

The dust collected in the precipitators is discharged to the pyrophoring kilns where it is oxidized and conveyed to the mixers and briquetting machines.

Open Hearth Precipitators

The open hearth dust precipitator (Fig. 4) which we first installed in 1950 and 1951 will interest you for several reasons. First, this was the initial commercial electrical precipitator installation for the control of open hearth dust. Second, it was a very successful application. Third, the stack emission from open hearth furnaces varied widely in concentration from 0.18 to 1.2 gr./ft.^{3} during the normal heat. It is composed of fine fume and is therefore quite heavy in appearance.

The problem involves the cleaning of combustion gases from open hearth furnaces, usually oil or gas fired. The

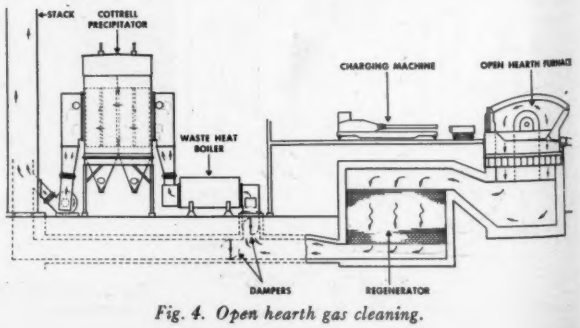

Fig. 4. Open hearth gas cleaning.

gases (in passing through the furnace) pick up metallic oxides which are carried as suspended solids. The material collected is a heterogeneous chemical mixture consisting largely of zinc, iron, lead and sulfur.

The suspended material, being a result of the fuming operation, is relatively fine, as shown below:

Particle Size Distribution

1.0 - 3.0 μ	7.3%
0.5 - 1.0 μ	28.4
0.15 - 0.5 μ	49.5
Below 0.15 μ	14.8

Each of the four furnaces on this installation has a normal rated capacity of 58 tons of cold metal per heat, the heat lasting approximately 8 hr. The furnaces are fired usually with gas, though in the winter 100% oil firing is common practice. At other times, combinations of gas and oil may be used. The gases leave the furnace at approximately 1200°F. and are cooled by a waste heat boiler to approximately 450° F. The amount of steam recovered is, of course, a very appreciable item in the overall economic picture.

According to the specifications of the purchaser, the dust concentration was to range between 0.17 and 2.0 gr./ft.^{3}, depending on the operating cycle of the furnace. This is roughly equivalent to 830 to 2400 lb./day. According to the contract, the suspended matter present in the exit gases from the installation could not exceed 11.5 lb./furnace for any one hour, including the precipitator rapping cycle and waste heat boiler lancing period. There was a further provision in the guarantee—the visual discharge could not exceed a No. 2 Ringlemann for more than 3 min. in any 1 hr.

The installation furnished by Research Corporation consists of a standard steel collecting plate, horizontal flow, fly ash-type precipitator and represents the most common type in use today. A waste heat boiler of about 10,000 lb./hr. capacity and an induced draft fan were also supplied for each furnace. Plate rappers are of the magnetic impulse, continuous operating type, and the high tension rappers are pneumatic vibrators operating on a time cycle.

Four precipitators were installed on the four furnaces during 1950 and 1951. These units operated very well, and stack appearance was satisfactory at all times. At no time during the normal cycles of operation did the stack discharge approach No. 2 Ringlemann; in fact, most of the time there was no visible discharge.

The dust concentration leaving the precipitators averaged 0.016 gr./ft.^{3} of dry gas at 60°F. and 30 in. mercury. This is equivalent to 2.3 lb./hr. and well below the specification. The actual precipitator efficiencies were about 98.5%.

The installation described incorporated what might be termed a unit system principle in that a separate precipitator was provided for each open hearth furnace. While

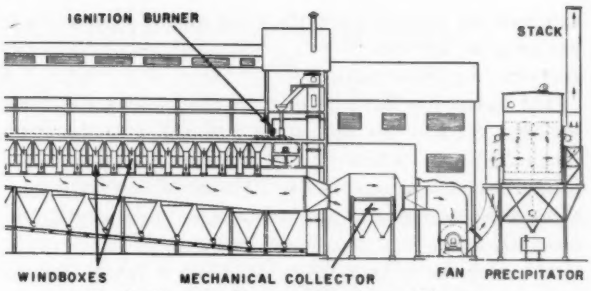

Fig. 5. Cleaning of iron ore sintering machine gases.

such an arrangement is satisfactory, recent studies which we have made indicate that in some cases it might be desirable, both from an economic and operational viewpoint, to combine gases from a number of furnaces and treat these gases in what might be termed a central cleaning plant. An advantage of such an arrangement is that the combining of the gases would tend to act as a leveling influence, resulting in more uniform gas and dust conditions over the various furnace cycles. This arrangement is entirely feasible and should be considered in analyzing future open hearth dust recovery problems.

Sintering Machines

The first precipitator for the recovery of dust from the combustion gases from iron ore sintering machines was placed in operation about two years ago. In view of the fact that the dust in the gases from these machines contains approximately 65% minus 44 μ particles, it was deemed desirable by the customer to install an electrical precipitator after a mechanical collector in order to reduce the amount of dust discharged to atmosphere. With the precipitator operating in series with the mechanical collector, the precipitator efficiency exceeded 95%, equivalent to an outlet concentration of 0.05 gr./scf. of gas.

The horizontal flow, plate type precipitator is used on this problem, with the gas discharging to atmosphere through an individual stub stack on each precipitator (Fig. 5). This recovery problem is unique in that much of the dust recovered in this operation is dust that has been previously collected in gas cleaning equipment in other locations of the steel plant. In other words, a large amount of sintering feed is obtained from the dust

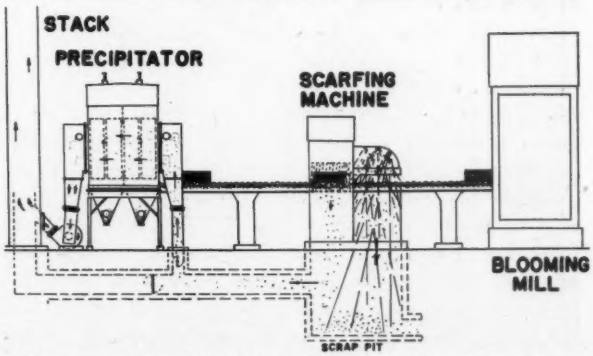

Fig. 6. Cottrell precipitator for cleaning hot scarfing machine gases.

catchers and precipitators operating on the blast furnace gas cleaning system.

Hot Scarfing Machines

The horizontal flow, plate type precipitator has been installed recently for the removal of fine particles from the ventilating system on hot scarfing machines. Two precipitators were furnished for this installation; one on a 45 in. slabbing mill and another on a 40 in. blooming mill (Fig. 6).

The fume from the scarfing operation is taken through underground ducts to the precipitator from which the clean gases are passed through a fan and are then exhausted to atmosphere through a steel stack. The installation and operation of a precipitator on the blooming mill scarfing machine is very similar.

Spot tests on the gases at the inlet to the precipitator indicate concentrations in the range of 0.4 gr./scf. While this is not a particularly high concentration, the characteristics of the material and small particle size make the stack discharge quite visible without collection equipment.

Cupola Installations

The material to be removed from cupola gas consists of a mixture of fume and dust particles and is composed primarily of oxides of iron and silica with small amounts of magnesium, aluminum, manganese and calcium oxides, and some carbon.

The gases leaving the cupola charge, combined with air inleakage through the charging door, produce secondary combustion. They are handled in one of two ways, as indicated below, depending upon the type of blast system used on the cupola.

In the cold blast system (Fig. 7), the cupola stack is capped and the gases which would normally be discharged are drawn off and conducted to the cleaning equipment. The temperatures at the cupola exit usually range from 1200° to 2000°F.

In the hot blast system, air for the cupola is preheated. Combustion gases from the cupola furnish the heat for the air preheaters, the cupola stack is capped and the gases are drawn off and sent to the preheaters, then to the cleaning equipment. Temperatures at the outlet of the preheaters usually range from 500° to 800°F.

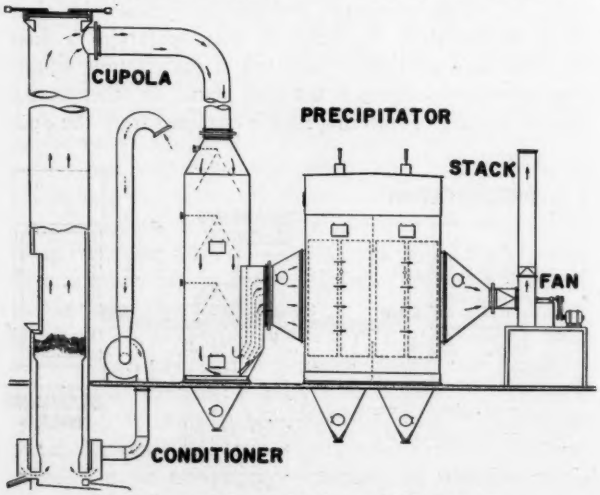

Fig. 7. Iron cupola gas cleaning—cold blast system.

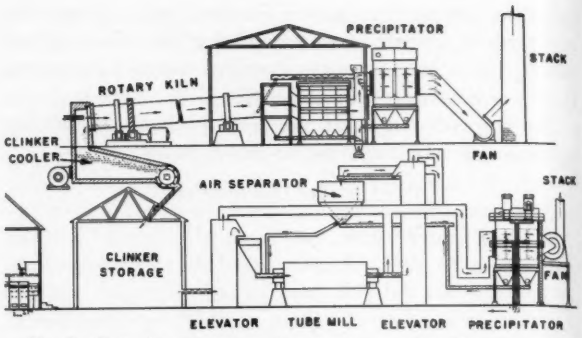

Fig. 8. Cottrell precipitators for cleaning cement kiln gases (top) and finish mill ventilating system gases (bottom) in a cement plant.

In both the hot and cold blast systems, the gas cleaning equipment is substantially the same. In both cases, it is necessary to pass the gas through spray cooling towers. This reduces temperatures to approximately 300° to 400°F. and increases the moisture content of the gas. With temperatures thus lowered and the water vapor content increased, the gases are properly conditioned for treatment in the precipitator. From the cooling tower, the gases progressively pass to the precipitator, fan, stack and atmosphere. Temperatures in the precipitator are maintained to insure the collection of dry material.

Of interest is the guarantee specified for one installation:

1. The exit gases from the installation for a period or periods aggregating not more than 3 min. in any 1 hr. will neither be (a) as dark or darker in shade as that designated as No. 2 on the Ringlemann Chart, as published by the U. S. Bureau of Mines, nor (b) of such opacity as to obscure an observer's view to a degree equal to or greater than that described in (a).
2. The suspended matter present in the exit gases in lb./hr. for any 1 hr. from the installation will not exceed the values given below under specified operating conditions as listed:

Production Rate Tons Iron/Hr.	Coke Ratio Tons Iron to Tons Coke	Gas Volume CFM. at 1500°F. Conditioning Chamber Inlet	Stack Emission Lb./Hr.
14	8 - 1	45,600	23
12	8 - 1	39,100	20
10	8 - 1	32,500	17.5

If production rate falls between the values set forth above, emission in lb./hr. may be interpolated.

These conditions were fulfilled to the satisfaction of plant and smoke authorities. As far as we know, electrical precipitation is one of the most satisfactory means of collection for this application at the present time.

(Concluded on page 170)

New Applications for Industrial Odor Control

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Until the last few years, both industrial management and the community considered odors to be the inevitable accompaniment of industrial activity. Odor conditions were accepted and considered to be something which could not be altered except by forcing the plant to move elsewhere. Naturally, people liked the increased employment and the payrolls which were spent in their community; so they endured the condition. Relatively recently, ways and means of correcting odor conditions have been developed, and the public is becoming aware of the fact that the mere presence of a plant in an area does not give that plant the right to make a nuisance of itself. Unfortunately, principles of odor abatement must be learned largely by trial and error because man has not yet built a machine to analyse or identify an odor which is as sensitive as the human nose. However, considerable work is being done in this field, and we have gone a long way in the last few years toward abating industrial odor.

There are many inter-related factors in the industrial odor problem. We have heard of some of these many times, such as inversions, other weather conditions, atmospheric interaction of the pollutants, etc. However, I would like to point out a few others, that most of us usually do not stop to consider:

1. Presence of Carriers. (Fig. 1) This plant is recovering chemicals in a furnace and even though the stack gases pass through Cottrell precipitators a considerable amount of fly ash escapes. Considerable odor is also formed in this operation and these small particles carry it long distances. Steam is dissipated in about 25-50 yards, leaving the white particulates. (Fig. 1).

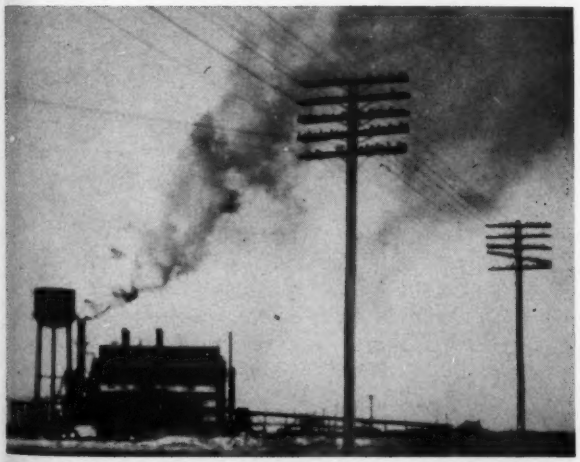

Fig. 1. Plant plume containing solid particles which carry absorbed odors.

2. Whether the Process is Continuous or not. Quite often odors are produced by a process at short intervals in the cycle of operation. Therefore, control of this condition is only necessary during these short periods.

3. Dilution of Odor Produced. Materials responsible for odor are frequently present in trace concentrations. Often there is no known method for actually determining these concentrations, but they are still detectable by the human nose.

4. Employee Odor Consciousness. Workers inside the plant are not conscious of the malodor. Sometimes they fear retribution from plant management if they mention the true conditions, but most likely they have become so accustomed to the condition that they are not conscious of its presence.

5. Physiological Effects. Persons affected by these odors react in many ways, such as nausea, difficult breathing, headaches, etc. In some instances, a malodor can disrupt the orderly functions of the body by interfering with sleep or causing the individual discomfort to an extent that he actually becomes neurotic and imagines ills which he attributes to his exposure to the odors.

6. Economic Cost. Capital costs for equipment to remove trace substances is high and many times it is impossible to build a unit which will do the job satisfactorily.

7. Physical State. Materials which produce the odor may be solid, liquid, or gaseous. (Fig. 2).

8. Background Odor. Considerable inplant odor is due entirely to lax housekeeping or improper maintenance of equipment. Spills or overflow of equipment contribute

Fig. 2. SO_2 fume leaving a storm sewer vent.

PROPERTIES OF MATERIALS

Masking Agents	Odor Counteractants
1. Substitution of a Second Odor	1. Chemical Counteraction With Odor
2. Requires Treatment of Entire Process	2. Treats Effluents Only
3. Additional Quantity for Spills	3. Nothing Additional Required for Spills
4. High Humidity or Rain Tends to "Wash Out" Agent	4. Material Unaffected by Rain or High Humidity
5. Required Quantity not Reduced by Installation of New Collection Devices	5. Quantity Needed Reduced as New Control Equipment is Installed
6. Difficult Control of Quantity Needed for Abatement	6. Easy Control of Quantity Necessary for Abatement
7. Final Abatement Results in Odor	7. Final Abatement Results in "Zero" Odor
8. High Cost of Equipment Installation	8. Low Cost of Equipment Installation
9. Cost of Operation Relatively High	9. Cost of Operation Relatively Low
10. Difficult to Re-locate once Equipment is Installed	10. Equipment Location Easily Changed
11. Automatic Operation Expensive to Attain	11. Automatic Operation Easy
12. Applicable to all Processes	12. Applicable Only When "Odor Opposite" is Known

as much odor, quite often, as the discharge of the plant stack. (Fig. 3).

For the purpose of this paper we will consider novel uses of masking agents and odor counteractants and their roles in the solution of odor problems. The use of these materials involves quite different handling, depending on which type is used. While it is true that quite recently improved systems have been evolved for spraying masking agents, many objections still remain to this type of odor control. The table below shows a comparison of masking agents and odor counteractants.

It must be remembered that in using masking agents the offensive odors are not combined with or destroyed as happens when an odor counteractant is used. Instead, the offensive odor is merely covered with a second odor which theoretically is pleasant smelling. In concentrated forms even these so called "pleasant odors" may exhibit highly offensive qualities and in some instances have proven to be nauseating to some of the workers handling them. The same may be said about excess amounts of odor counteractants, but if proper coverage or abatement is obtained one will not be able to perceive any odor, neither of the original offensive one nor of the counteractant.

In the application of these materials it has been found that in most instances space spraying procedures are most useful. While space spraying inside buildings or enclosures is not a new idea, the use of such a technique to treat large areas outside the plant is new. Overall plant odor abatement is accomplished by applying the material at sufficient locations so that it enters and mixes with the odors in all of the air strata in which they travel. In the Gulf Coast area a plant odor is transported by the wind over relatively flat terrain without very much lateral mixing. The spread of industrial odor from plants, forms a pie shaped wedge. Under some conditions of wind velocity this wedge is not over 5° and the concentration of the odor as it hits residential areas is not much different from that in the stack. Because of very frequent temperature inversions, it has been found in our area that tall stacks do not solve the plant problem, and hence are an unnecessary expense. Except for special conditions, the best odor abatement is obtained when the material is applied so that it can cover a broad area. For example, the best procedure is to locate the spray gun close to the top of the stack rather than in the stack because in the first instance it is possible to control more than the single stack. Often plant managers will point out a single stack as contributing all of the odor in the plant. When the condition has been abated at that point it has been found that due to housekeeping, spillage or some other reason, several other areas produce as much, if not more, odor than the original location. In other words, as the individual becomes more odor conscious he will find other sources of odor which he had not realized existed. Material should be applied in such manner that regardless of the wind direction there will be no polluted areas uncovered by the treating substance. Where spillage and overflows occur, one gun will cover an area of about 50 ft. in diameter if located 3 to 5 ft. off the ground. With increase in vertical height, the area covered will become larger accordingly.

Permanent installations for the equipment cannot be selected immediately because the physical structures in

(Continued on page 170)

Fig. 3. Spillage of rendered fats along a R.R. siding.

The Automatic Filter Paper Sampler in an Air Pollution Measurement Program

CHARLES W. GRUBER
Chief Smoke Inspector
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Assistant Engineer
Cincinnati, Ohio

The Cincinnati Bureau of Smoke Inspection has set out to determine the make-up and behavior of the air pollution that envelopes our community. Our studies are concerned mainly with the nuisance aspect of air pollution and in particular, the soiling effect. The program is a modest one, in charge of a chemical engineer, with one smoke inspector assisting him. We hope some day to have the answer to the question of just how clean or how dirty is the air over Cincinnati as a whole and how one neighborhood compares with another. We even dare to hope that some day we shall be able to compare the air pollution level of Cincinnati with a limited number of like communities.

There is great need for factual information. Evaluation by the people themselves is entirely subjective to their own experience and environment. We find this particularly true when a person moves from one neighborhood to another, or from one city to another. Their new home is either clean or dirty as measured by their past experience. A Cincinnati family moved a thousand yards from one home to another and became entirely dissatisfied with the neighborhood air pollution situation. In such a case, facts are needed to compare the former location with the new and to determine whether or not the new location is as dirty as the citizen complains.

Those who are engaged in air pollution abatement know that these are not $64.00 questions, but more like the million dollar variety. If the variations in the air pollution level of a community were a function only of the rate of production of pollution, one might be able to cut off a zero from that million dollar estimate. However, it is a well established fact that weather must be reckoned with. Pollutants are being dumped into a constantly changing envelope, above and around us. One hour it might be a swiftly flowing, turbulent stream and the next six, or twenty-four or forty-eight hours it might be a stagnant pool; it might flow from north to south or south to north, or it might flow in four directions at once; it might start to move in one direction and then change its course 180° without notice and pile up its entire pollution load in the process; it might start into the upper atmosphere and keep going or it might start in that direction and return to damage the unsuspecting. It is not the measurement of the pollution level per se that poses the crux of the problem but the correlation and understanding of the weather influences on the pollution build-up and carry-away in the everchanging, aerial sewage system. The experience of weather influences is not gained in a week, a month or a year. It takes decades for unusual conditions to occur and re-occur. Hence, it is important that sampling start today, as every day delayed is a day lost forever.

Budgets of air pollution abatement departments are usually limited. Instruments and techniques used to arrive at the answers we seek must be moderate in cost and capable of being manned with limited personnel. In a study of the soiling effect of air pollution, two separate phases of the problem must be considered. One phase is the minute smoke and dust particles which remain in suspension until they are deposited on walls, curtains, interior and exterior surfaces; the other is the heavy solids which settle out as dust, grit or fly ash on porches, window sills and bright, shining, light colored automobiles.

This paper is concerned with a study of the former type of soiling effect, i.e., suspended, particulate matter. We have selected as our instrument for doing this job the AISI automatic smoke sampler developed at Mellon Institute and described by Mr. Hemeon at the APCA meeting in Baltimore last year[1-2-3]. This instrument affords a continuous, automatic record of suspended smoke and dust particles. It is relatively inexpensive and it requires little man power to operate and evaluate the results.

Cincinnati put its first AISI automatic smoke samplers into service on January 29, 1952. Additional samplers were added from time to time as needs required and budget permitted. At present, there are 6 samplers in service, 3 of our own and 3 on loan from a courteous industrial neighbor. A sampling period of 6 hours has been selected in order to get results from a minimum number of samples. The time periods are numbered from 1 to 4, from midnight to 6:00 a. m.; 6:00 a. m. to 12:00 noon; 12:00 noon to 6:00 p. m.; and 6:00 p. m. to midnight. The air flow rate varies with each sampler so that it is necessary to establish a calibration curve for each sampler when com-

(1) Hemeon, W. C. L., "Instruments for Automatic Air Pollution Measurements", *Proceedings 44th Annual Convention Air Pollution and Smoke Prevention Association of America*, 1951, Roanoke, Virginia, pp. 115-123.
(2) Hemeon, W. C. L., Sensenbaugh, J. B., and Haines, G. F., Jr., "Design and Use of Equipment in Air Pollution Measurements". *Instruments*, 26, 566 (April, 1953).
(3) Hemeon, W. C. L., Haines, George F. Jr., and Ide, Harold M., "Determination of Haze and Smoke Concentrations by Filter Paper Samplers." *Air Repair* 3, pp. 22-28, August, 1953.

paring one with another. This procedure will be discussed later in the paper.

The variation in soiling effect on the test spots shows up as different shades of gray to black. The shade of the spot is evaluated by the use of reflected light with a "photo volt" reflectance meter. The results are calculated and reported as "dirt shade", a cumulated or total value for a 6 hour period, or as RUDS/10,000 linear ft. of air, a unit value of the soiling index.

It has already been shown that light reflectance and light transmission correlate very well and can be used interchangeably in the determination of optical density ($\log \frac{I_o}{I}$). In order to obtain whole number values of "dirt shade", optical density is multiplied by a constant k equal to 100.

$$\text{Dirt shade} = \text{Log}_{10} \frac{\%\text{ reflectance clean filter paper}}{\%\text{ reflectance soiled filter paper}} \times 100$$

In practice, the "% Reflectance Clean Filter Paper" is set at 100 on the reflectance meter. By this determination, a "dirt shade" of 0 is absolutely clean, while a "dirt shade" of 100 is absolutely black. It would be theoretically possible to get a "dirt shade" of higher than 100, but in 2 years of sampling (over 3,000 samples) the dirtiest spot for any one six-hour period gave a reflectance value of 11%. Round this value off to 10% and we would have

$$\text{Dirt shade} = \text{Log}_{10} \frac{100}{10} \times 100 = 100$$

The spot referred to above, having a reflectance value of 11%, is equal to a "dirt shade" of 96 for Period 2, recorded on November 13, 1953. "Dirt shade" values of less than 5 have been recorded on a number of days, thus indicating that the range of 0 to 100 is a practical set of limiting values.

From the first sampling until the latter part of 1953, data has been carried as "dirt shade" which is the "cumulated" value for the six-hour sampling period at the sampling rate of the particular instrument used at the station. The early instruments had separate pumps and flow rates were adjusted uniformly between samplers. However, as later models had self-contained pumps which are non-adjustable and which varied rather widely in unit flow rate, it became necessary to utilize a unit value in order to compare the results of the several instruments. Mr. Hemeon[2] showed that a unit value could be established and called it the COH unit/1,000 linear ft. of air through the filter paper. Thus, the variables of sampling time, sampling rate and spot size are eliminated and the results are reduced to a unit value and, therefore, comparisons can more accurately be made.

In the same manner, "dirt shade" can be reduced to a unit value. Because "dirt shade" is evaluated by reflectance, we have christened this unit "RUDS" (Reflectance Units of Dirt Shade) and will refer to it as a "Soiling Index". In order to have whole numbers ranging from 0 to approximately 100, we have chosen to use RUDS/10,000 linear ft. instead of 1,000 linear ft., thereby eliminating the decimal point.

In practice, it has been found important periodically to calibrate the instruments through a range of "spots" to determine the flow rate of the instrument versus the density of the spot. When this is done, RUDS can be calculated. For example, the BSI sampler No. IV has an average flow rate of .214 cfm. through 1 in. diameter spots having "dirt shade" values between 0 and 10. This represents 14,000 linear ft. of air in 6 hr. Thus, "dirt shade" values are converted directly to RUDS/10,000 ft. of air by dividing by 1.4.

$$\text{Sample calculation, } \frac{.21 \text{ cfm.} \times 60 \text{ min.} \times 6 \text{ hr}}{5.47 \times 10^{-3} \text{ ft.}^2 \text{ (Area of 1 in. Dia. Spot)}} = 14{,}000 \text{ linear ft. of air}$$

Dirt shade of $7 \div 1.4 =$
Soiling Index of 5 RUDS/10,000 linear ft.

Our long experience with monthly dust fall measurement techniques, having a very high degree of susceptibility to local influences at the sampling station, flashed the yellow light before us and we proceeded with caution before accepting the results of the AISI sampler. We were extremely anxious to know how critical is the sampling station exposure and how reproducible the results would be. Our experience indicates that the sampling station can be selected with a great deal of freedom and the results obtained will reflect a large area rather than a limited one as in the case of dust fall measurements. The direct path of a smoking chimney must, of course, be avoided.

In order to evaluate the instruments, simultaneous sampling by two instruments in various situations have been made:

1. Two instruments placed side by side on the roof of the Bureau of Smoke Inspection.
2. One sampler located on the roof of the BSI and one on the outside of the laboratory window on the sixth floor.
3. At the BSI location, one outside and one in the office on the fourth floor.
4. In a residential area, one outside and one in the living room of a residence.

The results of the foregoing special checks indicate that the sampling site is not critical and that the pollution being measured is uniformly distributed in the area and is not particularly influenced by local objects. The outside-inside tests are particularly significant in this regard.

A detailed description of the entire sampling program over the two year period would be too lengthy. The results of the sampling program are presented in the fol-

2. See footnote (2) page 143.

lowing graphs and tables.

In summarizing the two years of experience with the AISI automatic filter paper sampler, it is possible to make the following conclusions:

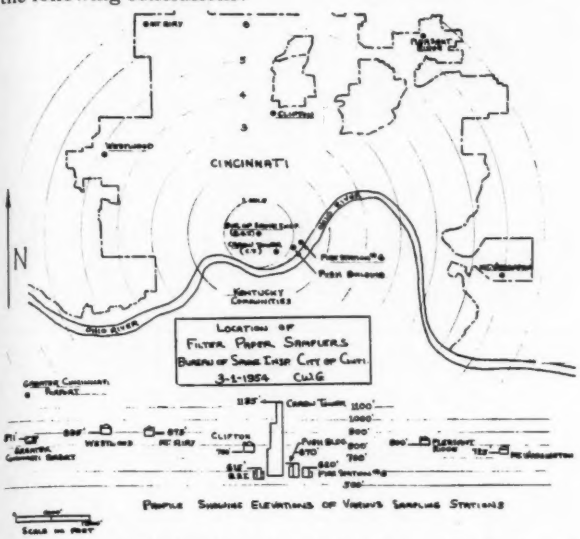

Fig. 1. Map of Cincinnati showing the locations and evaluations of the various sampling stations.

TABLE I

Samplers Outside and Inside at Bureau of Smoke Inspection Location — One on Roof Above 6th Floor, One in Office 4th Floor

1952 Oct	Dirt Shade Values—Outside/Inside				Difference[a]			
	Periods				Periods			
	1	2	3	4	1	2	3	4
28	17/17	38/34	29/29	31/35	0	+4	0	—4
29	30/30	35/43	35/30	46/55	0	—8	+5	—9
30	36/41	42/51	47/40	49/51	—5	—9	+7	—2
31	36/38	44/43	45/43	45/47	—2	+1	+2	—2
Nov.								
1	36/38	46/45	37/36	50/43	—2	+1	+1	+7
2	32/44	42/44	23/31	22/29	—12	—2	—9	—7

[a]Difference—Outside greater than inside values are +.

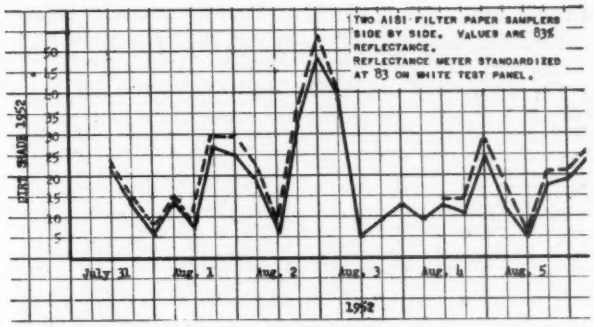

Fig. 2. Two instruments side by side on the roof of the BSI, results are "dirt shade" values as determined in 1952. ("Dirt shade", 1952, is not comparable with "dirt shade", 1953).

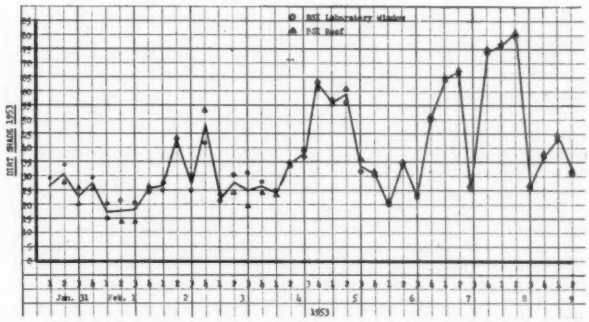

Fig. 3. One instrument on the Bureau of Smoke Inspection roof and one outside the laboratory window on the sixth floor. Results shown as "dirt shade" values, 1953.

(1) The AISI sampler is a practical instrument for the average air pollution control department for evaluating the soiling effect of the suspended particulate fraction of air pollution.

(2) The sampler must be given adequate maintenance and must be calibrated from time to time against spots of various densities.

(3) The sampling station is not critical and when a few precautions are exercised, one sampling station will indicate pollution levels for a neighborhood of like pollution exposure.

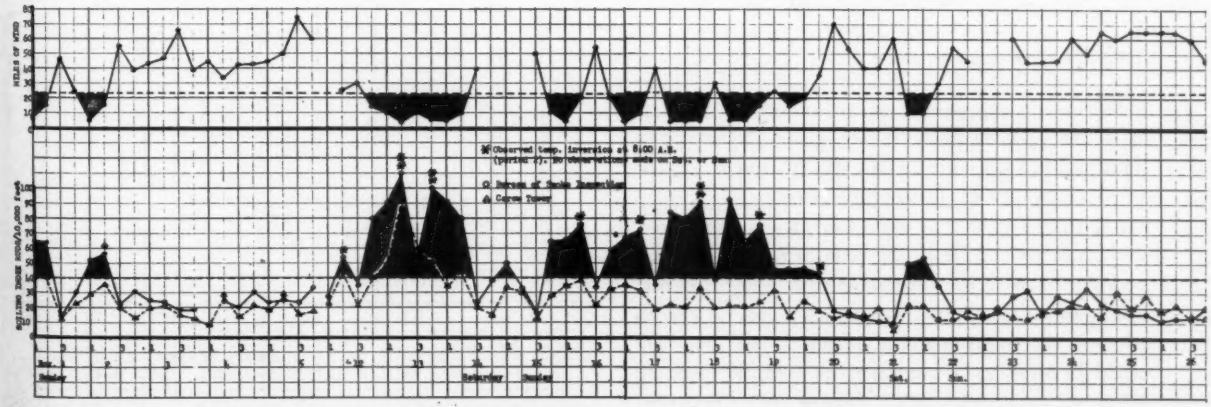

Fig. 4. Two samplers at downtown locations, at different elevations are shown in RUDS/10,000 linear ft. of air, period by period. Also (BSI, 85 ft. above grade, Carew Tower 580 ft. above grade). Results shown are miles of wind and observed temperature inversions.

TABLE II

Sampler Outside and Inside Suburban Residence[a]

1953 Jan.	Dirt Shade Values—Outside/Inside				Difference[b]			
	Periods				Periods			
	1	2	3	4	1	2	3	4
13	30/25	41/29	31/24	33/24	+5	+12	+7	+9
14	33/27	28/23	18/18	15/17	+6	+5	0	—2
15	13/14	14/14	15/17	11/12	—1	0	—2	—1
16	9/10	14/14	12/14	12/14	—1	0	—2	—2
17	9/9	16/13	26/21	15/22[c]	0	+3	+5	—7[c]
18	17/13	26/19	23/17	41/29	+4	+7	+6	+12

(a) Outside Sampler, 1⅛ in. dia. spot, 72 cu. ft. in 6 hrs., 10,300 linear ft. of air. Inside Sampler, 1 in. dia. spot, 54 cu. ft. in 6 hrs., 9,800 linear ft. of air.

(b) Difference—Outside greater than inside values are +.

(c) Family Party.

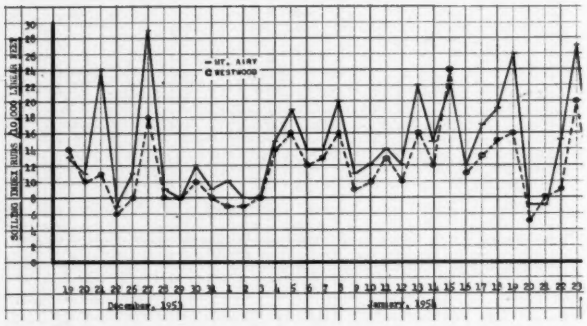

Fig. 5. Two samplers at two different residential areas (Westwood and Mt. Airy), separated by approximately 4 miles. Each residential area has relatively the same air pollution exposure. Results in RUDS/10,000 linear ft.

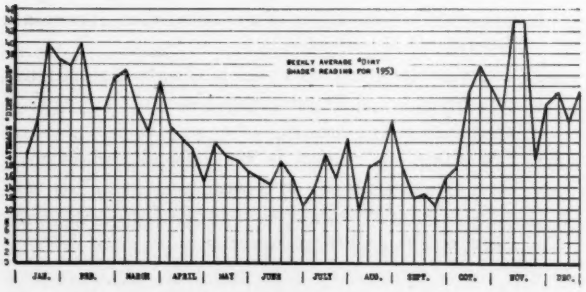

Fig. 6. Weekly average, "dirt shade" values for one year, 1953, for the BSI location. Results in "dirt shade", 1953.

(4) Results of the sampling program should be reported as RUDS/10,000 linear ft. for spots evaluated by light reflectance and COHS/10,000 linear ft. for spots evaluated by light transmission.

(5) No comparison of the pollution level of one area with another can be made without qualifying that comparison with weather influences.

(6) Soiling index can be used to furnish a general knowledge of the build-up of pollution in an area and could be used as a guide in the establishment of other sampling programs. This is very important as sampling programs for fumes, odors and other

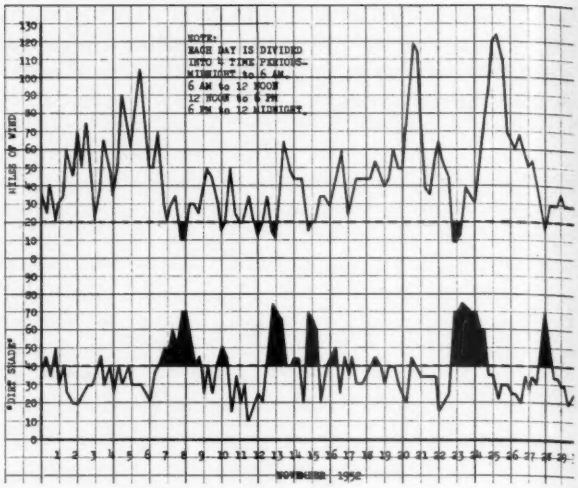

Fig. 8. Dirt shade vs. wind, November, 1952.

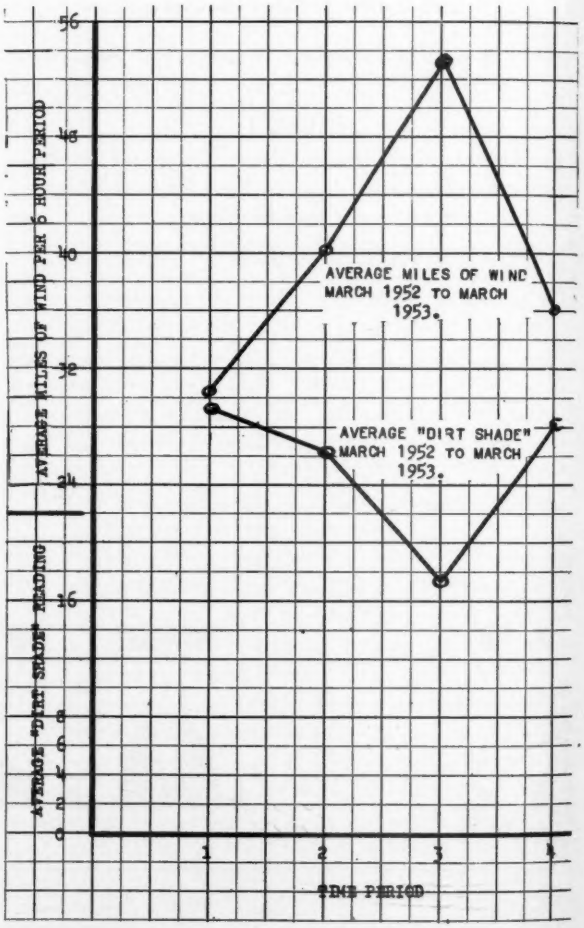
AVERAGE MILES OF WIND PER 6 HOUR PERIOD
AVERAGE "DIRT SHADE" READING
AVERAGE MILES OF WIND MARCH 1952 TO MARCH 1953.
AVERAGE "DIRT SHADE" MARCH 1952 TO MARCH 1953.
TIME PERIOD

Fig. 7. Average "dirt shade" for one year versus miles of wind for each time period of the day. BSI location.

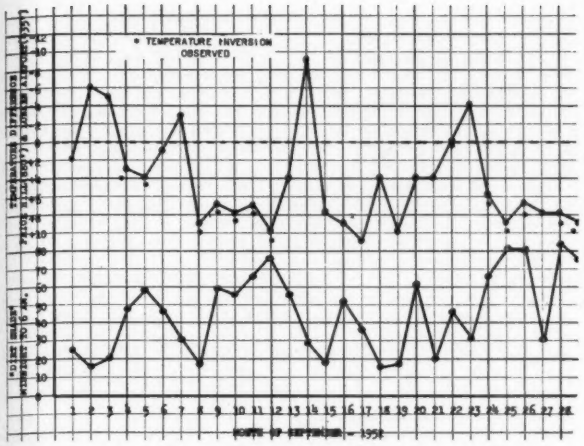

Fig. 9. "Dirt shade" versus temperature difference, indicating temperature inversion, for the month of September, 1952, for period 1 only, BSI location. Values in "dirt shade", 1952.

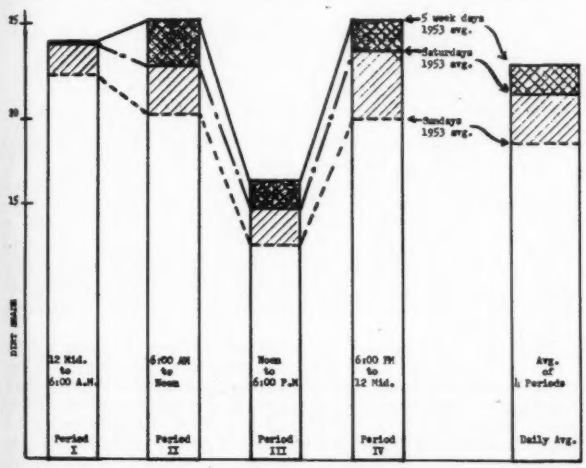

Fig. 10. Graphic representation of the data in Table III.

TABLE III
Yearly Average "Dirt Shade" Values

Period	Mon.	Tues.	Wed.	Thurs.	Fri.	Average 5 Week Days	Sat.	Sun.
I	22.3	22.6	25.6	26.3	25.3	24.4	24.6	22.4
II	24.8	26.0	26.5	26.6	24.8	25.7	23.1	20.2
III	17.5	15.2	16.5	15.8	17.7	16.5	14.6	12.6
IV	25.3	25.2	26.0	26.5	25.9	25.8	24.0	20.0
Average	22.5	22.5	23.6	23.8	23.4	23.2	21.6	18.8

Table III. Yearly average "dirt shade" (1953 values) by days of the week and by periods from April, 1952 to April, 1953, for the BSI location. Significant fall off in pollution levels on Saturday and Sunday is indicated.

suspended pollutants are very expensive and time consuming. The soiling index will afford information so that maximum benefit can be obtained from other sampling programs.

DISCUSSIONS OF PAPER ENTITLED "THE AUTOMATIC FILTER PAPER SAMPLER IN AN AIR POLLUTION MEASUREMENT PROGRAM" BY C. W. GRUBER AND E. L. ALPAUGH

We were very much interested in the report by Messrs. Gruber and Alpaugh on their studies employing the AISI Automatic Smoke Sampler which was developed in our laboratories at Mellon Institute. Before embarking on a discussion of the findings reported which are in agreement with data obtained in our laboratories, we should like first to offer a note of caution on one point. In the paper we presented at this meeting a year ago, we did demonstrate that the quantity of smoke is proportional to optical density but only when the blackness of the spot is not excessive. Many of the authors' smoke concentrations are far in excess of the limit within which the rule of proportionality applies and while this does not invalidate any of their conclusions, we should like to emphasize this point for the benefit of others who may conduct similar studies. The excessive smoke deposit on a single spot stems from the use of a 6-hr. sampling period which we had originally advocated before we realized the limitations just alluded to. A 2-hr. period will be found to be much more suitable for most localities. It has a further advantage in micrometeorological studies in that it displays more interestingly the hourly changes in atmospheric conditions which tend to be masked where the longer sampling period is used.

The instrument and the technique have two primary applications. One is in micrometeorological studies where it is desired to learn the relationship between intensity of smoke and weather influences; and the other is in providing a continuing historical record of the smoke concentrations in a particular locality (just as monthly dust fall records provide a basis for characterizing a locality in that respect). The historical record permits comparisons between various localities within a city and in different time periods and can also provide useful information on differences between cities provided that the results are evaluated on the same basis. The authors have seen fit to employ a reflectance measurement which unfortunately will not make it possible to compare Cincinnati's smoke record with that of numerous other cities which are at present uniformly engaged in a program of measurements using a system of evaluation based on determination of light transmission.

For purposes of historical record, we have been obtaining a continuous record of smoke concentrations in the Oakland section of Pittsburgh (a residential area within the city limits) as shown in the following table.

We have always been careful to qualify the significance of measurements made at our laboratories. We had been describing the concentrations obtained by our single instrument as applying only to that particular location. However, we recently placed another sampler in operation some ⅝ mile distant from our laboratories and were interested to discover (Fig. 1) that the concentrations at the two locations paralleled each other almost exactly and the average over a period of a month was practically identical. This permits us now to describe them as representative of this area of the city. This is confirmation of the observation made by the authors that "the sampling site is not critical and that the pollution measured is uniformly distributed in the area and is not particularly influenced by local objects."

Monthly Average Concentrations of Haze-Smoke in Oakland Section of Pittsburgh.

Concentration: COH units/1000 feet

Month and Year	Monthly Average	Max. For any 2-hr. per.	Min.	Max. For 24-hr. per.	Min.
December, 1952	6.5	9.1	1.4		
January, 1953	3.9	10.1	1.1	7.8	2.2
February, 1953	3.4	9.4	1.0	6.2	1.8
March, 1953	2.6	7.8	1.8	4.8	1.7
April, 1953	2.5	9.6	0.4	4.9	1.6
May, 1953	2.2	6.8	0.4	3.1	1.0
June, 1953	2.2	7.6	0.4	4.0	1.2
July, 1953	2.2	7.5	0.2	3.6	0.9
August, 1953	2.5	6.6	0.2	5.3	0.9
September, 1953	2.2	6.6	0.2	3.7	0.7
October, 1953	3.4	7.4	1.4	7.4	1.4
November, 1953	3.7	10.1	1.5	10.1	1.5
December, 1953	2.8	11.3	0.9	8.5	1.5
January, 1954	3.1	10.6	0.9	5.6	1.9
February, 1954	3.2	9.2	0.8	5.4	1.6

When another instrument was placed four miles away from our laboratory location, an even more striking fact was discovered (Fig. 2).

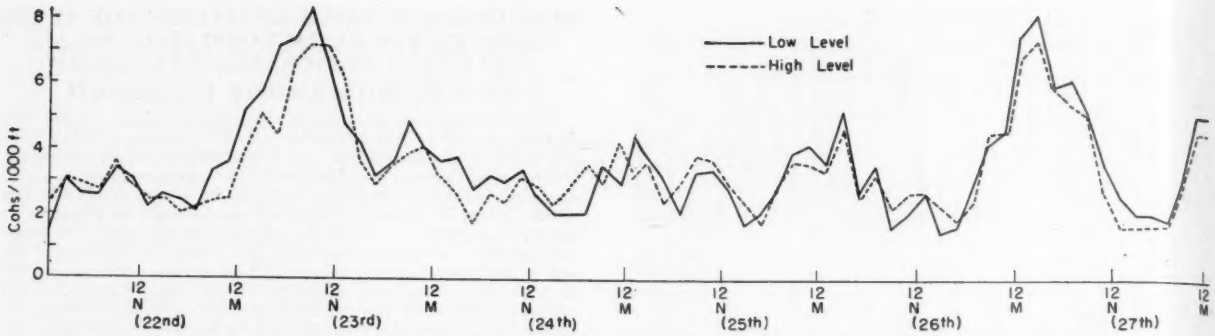

Fig. 1. Relative concentrations of smoke in two Oakland (Pittsburgh) locations ⅜ mile apart and 150 ft. elevation difference.

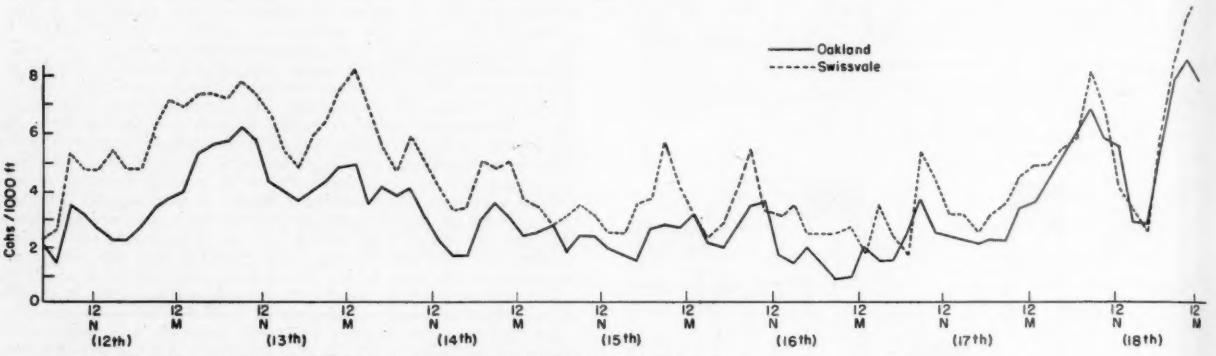

Fig. 2. Relative concentration of smoke in two regions of Pittsburgh 4 miles apart.

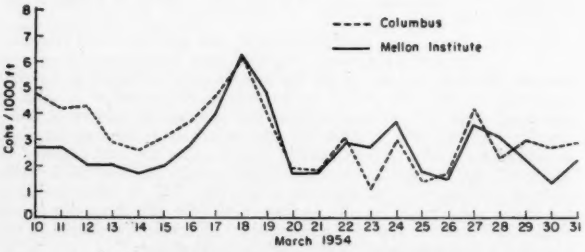

Fig. 3. Relative smoke concentrations in Columbus, Ohio, and Pittsburgh, Pa., Mar. 10-31, 1954.

Even with this distance of separation it was noted that changes in concentrations from hour to hour were parallel although in this instance the Swissvale location had a consistently higher concentration of smoke or haze.

In processing some data obtained recently from Columbus, Ohio through the courtesy of Mr. Herbert Johnson, we unexpectedly discovered the amazing facts illustrated in Fig. 3. In this case, 12 2-hr. samples for each 24-hr. period have been averaged. As can be seen, changes in smoke concentrations from day to day are almost exactly alike, even though the two cities are separated by a distance of 200 miles.

It is quite obvious from these results that the changes shown on these graphs are not those due to change in rate of smoke or haze production nor, for the most part those resulting from changes in wind direction; rather, they must be due to changes in the vertical structure of the atmosphere which determine the efficacy with which pollution at ground level is dispersed and diluted by vertical wind currents. We think the implications of these findings will be far reaching in their application to micrometeorological studies.

W. C. L. Hemeon
Harold M. Ide
Mellon Institute
Pittsburgh, Pa.

The authors are to be complimented on their excellent paper. It is gratifying to know that a practical unit is now available for determining the relative amount of pollutants in the air by a continuous sampling method.

Referring to the authors' figures 3 and 4, figure 4 shows a great difference in dirt shade, as one would expect, between high and low elevations. Figure 3 shows little difference in dirt shade between roof and window locations in the same building. We believe that variations in dirt shade between various parts of a building and between various buildings should be further investigated. It would appear logical that aerodynamic effects of building structures as well as localized concentrations of dirt caused by traffic and other nearby sources of suspended particulate matter would have considerable effect on the dirt shade at certain sampling points. We have observed particularly that traffic has a great effect on the soiling of buildings and might also have a great effect on dirt shades recorded.

The authors show a correlation between dirt shades and wind velocity. Although we have collected data only over a short period of time our meager data indicates that dirt shade is influenced by wind direction at our present sampling station. This effect is undoubtedly caused by the great variation in air pollution sources in different directions from the sampling station. No doubt a sampling station could be selected where air pollution sources are more nearly equal in all directions, which would tend to eliminate the effect of wind direction. The average dirt shade at sampling stations where the prevailing wind over the station carries air from open country should not be included in averages of stations in the city. One of the most interesting aspects of automatic sampling will be the degree of correlation between dirt shade and visibility over a long period of years.

H. C. Johnson
Division of Smoke Regulation and Inspection
Columbus, Ohio

There has been in recent years a marked tendency to improve observational and measurement methods for air pollution investigations. The present paper is welcome as an example of the use of these improved methods in actual field studies.

Two features of the paper are of special interest to the writer. The first is the strong emphasis of the authors on the primary importance of weather factors in any evaluation and interpretation of air pollution conditions. Such an emphasis is badly needed: meteorology at the

present time is making only a fraction of the contribution that it is capable of making.

The second point of interest is the simultaneous measurements of soiling inside and outside a building, as given in Tables 1 and 2. The main portion of the differences shown are no doubt attributable to meteorological conditions, the most important of which is probably turbulence. Although a steady wind transports gases and aerosols into and out of buildings, the turbulent fluctuations of the wind exert a sort of pumping action around windows, doors, and other portions of the structure which is very effective. At the present time the writer is supervising a research project sponsored by the Geophysics Research Directorate of the Air Force Cambridge Research Center in which the rates of penetration of allergenic pollens and industrial smokes into buildings are being investigated in relation to the existing meteorological conditions. The air of the room is first cleaned by suitable equipment, then simultaneous measurements of concentration made at intervals inside and just outside the room. From these and simultaneous meteorological measurements which are also taken, the rate of penetration will be analyzed in terms of wind speed, direction, and turbulence. The investigation has not proceeded far enough to permit the presentation of actual detailed results.

In Figs. 4 and 9 the influence of the atmospheric stability associated with inversion conditions in permitting the accumulation of high concentrations of soiling particles is clearly brought out. The association between wind speed and "dirt shade" is shown in Figs. 7 and 8. However, the wind speed is clearly not the primary factor here. Roughly speaking, atmospheric turbulence and mixing increase with the wind speed, and these figures reveal that relationship. If atmospheric turbulence had been measured directly, instead of wind speed, an even closer relationship would be anticipated.

E. Wendell Hewson
University of Michigan

This paper presents a considerable amount of interesting data on the fluctuations of the levels of fine suspended, particulate matter in the atmosphere at various sampling points in the city of Cincinnati by means of the Hemeon automatic smoke sampler. The principle of filtering fine smoke or suspended dust particles in measured quantities of air through filter paper in a continuous manner was first employed by Owens[1]. A more elaborate instrument which yields spots of one in.^{2} on filter paper on an hourly basis for reflectance measurements and at the same time filters a parallel sample of air over a 24-hr. period for weight determination has been developed recently by Hall[2]. Wilson[3] uses reflectance as a measure of the intesity of the spot or stain in a simple instrument similar to that designed by Hemeon.

In the Windsor-Detroit international investigation we have employed both the Owens and Hall instruments, as well as the High Volume Air Filtration Sampler in studies on suspended particulates[4]. More recently a number of Hemeon samplers have been operated.

The "dirt shade" or "RUDS" (Reflectance units of dirt shade) introduces a new unit in the measurement of the soiling of filter paper. Two other units are already in use, the Coh unit of Hemeon[5] and the km unit for Hall.

A Coh unit is defined as that quantity of light scattering solids producing an optical density equivalent of 0.01 when measured by light transmission. For convenience, Hemeon reduces all results to multiples of 1000 linear ft. of air so that the concentration for any time period may be described in multiples of Coh units per 1000 ft. of air.

The km unit represents that deposit required to produce an optical density equivalent (D_E) of 0.1 when the deposit area is 1 cm.^{2} and the volume of air sampled is 1 m^3; where D_E is measured by reflectance at 400 mμ. With all other factors constant, there is a linear relation between these two units, i.e., km/Coh per 1000 ft. = 3.29.

The dirt shade unit of Gruber and Alpaugh is represented as that deposit to produce a D_E of 0.01 where D_E is measured by reflectance. However, these authors use as their soiling index Reflectance Units of Dirt Shade per 10,000 ft. of air. The scale is thus approximately 10 times that given by Coh units.

According to the values given by Gruber and Alpaugh in Figs. 3, 8 and 9, dirt shade units up to 80 have been measured by using a sampling cycle of 6 hr. This corresponds to a reflectance of 16%. Hemeon has shown that there is a straight line relationship between smoke quantity and optical density (transmission) for values of optical density up to 0.301 or 50% light transmission (30.1 Coh units). This indicates the applicability of Beer's law for low optical densities. Wilson[3] employing light reflectance methods has also found this linear relationship to hold in the above range. Beer's law however cannot be applied with any accuracy to measurements of reflectance or transmission below 50 percent.

The accuracy of the results would be improved by cutting down the sampling time from 6 hr. to 1, 2 or 3 hr. in duration in order to avoid sample spots of excessive optical density.

It is stated that light reflectance and transmission measurements correlate very well and can be used interchangeably. This statement is only approximately true for low optical densities in the range where Beer's law is valid. Hemeon has shown that there is a fairly linear relationship between these two sets of measurements, but that the

TABLE 1.

Comparison of Reflectance and Transmission Readings on Suspended Particulate Matter Samples Collected by Hall-Chaney Auto-Sampler in Windsor, Ontario. (Measurements of spots on Filter Paper made with Light at Wave-length of 400 mμ.)

Feb. 16-17, 1953				Feb. 17-18, 1953				Feb. 18-19, 1953			
Filter No.	Optical Density Equivalent for Reflectance D_ER	Optical Density Equivalent for Transmission D_ET	D_ER times 0.54	Filter No.	Optical Density Equivalent for Reflectance D_ER	Optical Density Equivalent for Transmission D_ET	D_ER times 0.54	Filter No.	Optical Density Equivalent for Reflectance D_ER	Optical Density Equivalent for Transmission D_ET	D_ER times 0.54
1	0.235	0.128	0.127	6	0.110	0.064	0.059	1	0.172	0.095	0.093
3	0.180	0.106	0.097	7	0.090	0.046	0.049	2	0.186	0.104	0.100
4	0.205	0.107	0.111	8	0.115	0.065	0.062	4	0.168	0.111	0.091
5	0.180	0.085	0.097	9	0.122	0.065	0.066	6	0.155	0.084	0.084
7	0.240	0.127	0.130	10	0.120	0.071	0.065	7	0.160	0.090	0.086
8	0.178	0.083	0.096	11	0.160	0.082	0.086	8	0.211	0.125	0.114
9	0.154	0.071	0.083	12	0.169	0.095	0.091	9	0.175	0.098	0.095
11	0.180	0.093	0.097	14	0.210	0.109	0.113	10	0.190	0.103	0.103
12	0.184	0.086	0.099	15	0.195	0.108	0.105	11	0.191	0.119	0.103
13	0.151	0.071	0.082	16	0.190	0.119	0.103	12	0.241	0.142	0.130
14	0.170	0.086	0.092	17	0.205	0.108	0.111	13	0.236	0.118	0.127
15	0.136	0.062	0.073	19	0.186	0.103	0.100	14	0.223	0.130	0.120
16	0.128	0.060	0.069	20	0.208	0.119	0.112	15	0.183	0.111	0.099
17	0.126	0.054	0.068	22	0.265	0.130	0.143	16	0.191	0.118	0.103
18	0.135	0.064	0.073	23	0.195	0.122	0.105	17	0.194	0.106	0.105
19	0.122	0.059	0.066	24	0.208	0.117	0.112	18	0.180	0.102	0.097
20	0.125	0.058	0.068	25	0.182	0.102	0.098	20	0.195	0.114	0.105
21	0.134	0.063	0.072					22	0.270	0.140	0.146
23	0.140	0.065	0.076		Mean	0.096	0.093	23	0.325	0.175	0.176
25	0.123	0.054	0.066					24	0.356	0.188	0.192
	Mean	0.079	0.087						Mean	0.119	0.113

transmission is more sensitive for light deposits on the paper.

The following data, taken from a recent paper by Katz and Clayton[4], shown in Table I, indicate the relation between reflectance and transmission readings on suspended particulates in the Windsor area in a range of hourly samples collected with the Hall instrument. The optical density and reflectance values were determined in a Beckman spectrophotometer at a constant wave length of 400 mμ. A comparison of the results under the heading "Optical Density Equivalent for Transmission (D_ET)" with the values in the last column, (D_ER x 0.54), for each series of samples, indicates fair agreement on the average, although the relation $\frac{D_ET}{D_ER} = 0.54$ does not hold rigidly, even in the comparatively low D_ET range shown here.

The authors show a striking correlation between soiling index or "dirt shade" and miles of wind in Figs. 4 and 7. The intensity of pollution by fine, suspended particulates in Cincinnati varies inversely as the mean surface wind speed. We have found a similar relation to hold for the Windsor-Detroit area. Fig. 9 shows also good correlation between "dirt shade" from midnight to 6 a.m. and temperature inversion conditions.

Cholak[6] (4) of the Kettering Laboratory University of Cincinnati, has recently compared the levels of suspended particulates and their composition, as well as the concentrations of a considerable number of gaseous pollutants, in the atmosphere of Cincinnati, with the corresponding values for a number of other cities in the United States. These studies by Cholak and his co-workers should be helpful to the present authors in providing an answer to the question as to the extent of atmospheric pollution in Cincinnati in relation to other industrial communties.

1. Shaw & Owens, "The Smoke Problem of Great Cities," London, Constable & Company, Ltd., 1925.
2. Hall, Stanley R., "Evaluation of Particulate Concentrations with Collecting Apparatus". **Anal. Chem.**, 24, 996-1000 (1952).
3. Wilson, W. L., Cleveland, Ohio. Private Communication.
4. Katz, Morris and Clayton, George D., "Instrumentation and Analytical Techniques for the Continuous Determination of Air Contaminants". **Proceedings, American Society for Testing Materials**, 1953, (in press).
5. Hemeon, W. C. L., Haines, George F. Jr., Ide, Harold M., "Determination of Haze and Smoke Concentrations by Filter Paper Samplers". **Air Repair**, 3, 22-28, August 1953.
6. Cholak, Jacob, "The Nature of Atmospheric Pollution in a Number of Industrial Communities", **Proceedings Second National Air Pollution Symposium**, pp. 6-15, May 1952. (Stanford Research Institute.)

Morris Katz
Advisory Board on Air Pollution
International Joint Commission
Ottawa, Canada.

Pittsburgh Coke & Chemical Co., although newcomers in the field of measuring fine suspended matter such as smoke, has been making dust fall measurements and recording weather data for some time.

Our studies of air pollution have been prompted by our relationship to our neighbors, a strictly residential area directly across the river from our plant. Recently, to supplement our dust fall studies, we put into service an A.I.S.I. Automatic Smoke Sampler. This sampler has been operating in our plant surrounded by coke batteries, blast furnaces, cement, activated carbon and chemical plants. In the future, it is planned to operate this or a second sampler at various locations throughout the adjacent communities.

Data obtained during the first month's operation has been compared with that obtained from a similar instrument operating at the Industrial Hygiene Foundation, Mellon Institute, in Pittsburgh. These two sampling points are approximately eight miles apart. The resultant spots were evaluated by light transmission and reported as COHS per 1000 linear ft. of air. The data shown in Fig. 1 follow a parallel pattern and in this case are almost identical. This seems further to indicate that a single sampling site may reflect a rather large area.

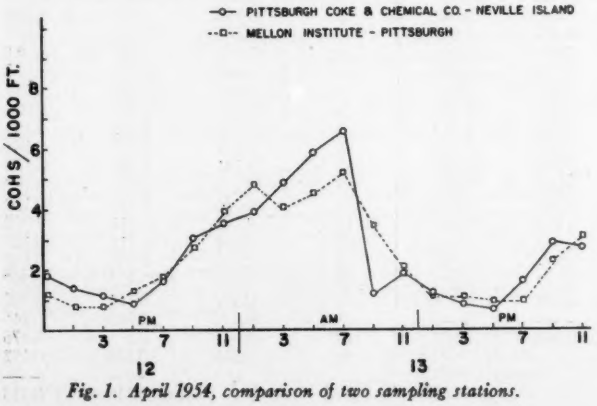

Fig. 1. April 1954, comparison of two sampling stations.

As of the present time, insufficient data has been obtained from our work to justify any conclusions. However, in the future, we will attempt to correlate wind velocity and direction with the COH readings.

As was pointed out by Messrs. Gruber and Alpaugh, there is need for a better understanding of weather influence on air pollution.

Richard I. Huling
Pittsburgh Coke and Chemical Co.
Pittsburgh, Pa.

It is encouraging to note the increased interest in the use of filter paper samplers. The encouragement is two-fold. First, spot or filter paper sampling is a relatively simple method for determining an important phase of air pollution, a phase which needs increased investigation. Second, the more persons interested and engaged in this type of sampling, the more ideas to further perfection and obtain maximum benefits.

The paper presented by Gruber and Alpaugh reveals the potentials this type of sampling has to offer. In their paper they have presented findings which should provide important information to both those now engaged in a spot sampling program and those considering one.

In December 1952 the Air Pollution Control District of Jefferson County purchased a continuous filter paper sampler. This instrument, although different in type, is identical in principle with the sampler described in the above paper. From December 1952 until August 1953 we attempted to use our instrument for the evaluation of soiling effects of atmospheric particulates by a continuous trace method rather than spots. The trace method did and still does offer an excellent monitoring device on a minute to minute basis. The evaluation of the trace was a purely visual one. At some future date we plan to release more information on our findings through the use of the trace.

It was in August 1953 that we began a spot sampling program, using Hemeon's[1] method of sampling and evaluation. In preparing for the program we outlined some objectives which we hope to attain. In the following list of those objectives you will no doubt notice that we differ to some degree with Gruber and Alpaugh.

Spot Sampling Objectives

1. To determine the staining properties of atmospheric particulates.
2. To compare the pollution levels of various areas within Jefferson County.
3. To determine the pollution level versus time and meteorological elements.
4. To translate the visual stain or spot into a recordable unit.
5. To attempt to correlate the spots with local domestic and/or industrial activity, in the case of the latter whether certain periodic processes influence the stain.
6. To use the accumulated data in determining improvement of an area. This must, of course, be determined over a long period of time.

Like many objectives we set, it takes considerable time to realize them fully. In order to explain better our reasons for setting forth the previous list of objectives I will attempt to define them in the order presented. It may be noted that our reasoning differs on some points from Gruber and Alpaugh.

Objective 1. Filter paper has long been used in determining the amount of fine particulates in the atmosphere. This is especially true in determining the efficiency of dust collectors. Investigations by Hemeon[1], Shaw and Owens[2] and Davidson[3] have proved the worth of filter paper samplers in determining pollution levels. Much of the spot produced can be attributed to the burning of fuels. However, particulates from other activities can also influence the density of the spot.

Objective 2. As one expects, various areas of a community will have different pollution levels. It is, however, difficult to evaluate properly the pollution level since its basis must first be established. Spot sampling coupled with other forms of sampling will provide the necessary information to indicate clearly the level of pollution. This basis will allow a more concrete comparison of areas. From such comparisons various standards of cleanliness can be set up for the respective areas.

Objective 3. As stated in the above paper, correlation of the spots with meteorological conditions is necessary if the results are to mean anything. Also stated in the paper was the fact that meteorological conditions can and do change within short periods of time. These two important facts show the need for shorter sampling periods. Another important reason for shorter sampling periods is that in evaluating the pollution level of an area, time plays a major role. This is true for two reasons: first, community activity is regulated for the most part by time; second, the diurnal and nocturnal changes during a 24 hr. period effect in varying degree the stability of the atmosphere, which in

(Continued on page 171)

BCR Activities for Cleaner Air: 1953 and 1954

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Bituminous Coal Research, Inc.
Columbus, Ohio

As the national research association for bituminous coal, Bituminous Coal Research, Inc., has for years conducted and sponsored projects seeking to reduce smoke and dust from coal-fired boilers. Furthermore, BCR has maintained a practice of disseminating information nationally on the results of such projects, as well as cooperating with organizations and individuals with similar interests. The motivation is to retain and expand the market for bituminous coal: BCR wants to help coal customers obtain from coal maximum satisfaction including the good will of their communities. The interest of BCR in air pollution, therefore, provides an important research objective.

Great Lakes Air Pollution Abatement Program

BCR has been a major supporter and participant in the so-called GLAPAP project. Its objective is the reduction of the smoke from 500 U.S. and Canadian coal-fired bulk carriers operating between ports on the Great Lakes. Three-fourths of these ships have hand-fired Scotch-marine boilers, and one-fourth are stoker-fired. Participating with BCR are the Lake Carriers Association, the Dominion Marine Association and the Coal Producers Committee for Smoke Abatement.

Steady progress is being achieved through the installation of overfire air jets and underfeed stokers in Scotch boilers. The advantages of closer compliance to recommended coal specifications is becoming recognized. Stoker-fired water-tube boilers are being equipped with overfire jets. Better communication between the ships' bridges and the boiler rooms is being established. Shore-to-ship telephone calls to non-complying vessels at the time of smoke observations is now the practice along the Detroit River.

As evidence of the progress, the following tabulation is quoted from a letter by Dr. Morris Katz, chairman of the Canadian Section of the Technical Advisory Committee of the International Joint Commission:

TABLE I.

Improvements in Smoke Conditions from Coal-Fired Vessels on the Detroit River

	Percent Time Correspopding to Ringelmann Number		
Year	No. 1 or lighter	No. 2	No. 3 or darker
1950	36.5	12.8	50.7
1951	47.1	18.15	34.75
1952	49.4	19.45	31.15
1953	59.8	12.7	27.5

General A. G. L. McNaughton, chairman, Canadian Section, International Joint Commission has also expressed appreciation by letter.

For more information on the program, as well as the personnel of the Engineering Advisory Committee, and the interest of the APCA, reference may be made to the annual reports of the APCA Marine Committee, of which Mr. John Brown is chairman.

Stack-Spray Dust Collection

At the suggestion of air pollution control officials attending the APCA Harrisburg meeting on September 24, 1953, and on the recommendation of H. B. Lammers of the Coal Producers Committee for Smoke Abatement, an experimental investigation has been started on stack sprays. L. A. Updegraff is the engineer conducting the project. The objective is to determine the optimum design and arrangement of water-spray nozzles for agglomerating and settling out flue dust into the base of the stack during soot blowing. The efficiencies of collection and the prevention of corrosion in stacks from such sprays are also to be investigated.

Many steam plants create little or no dust nuisance except during soot blowing. Dry-type dust collectors are a big help, of course, but not all plants have them, and others would not make the installations of high-efficiency dust collectors merely for soot blowing. Where dust collectors are in use, stack sprays would also be used during soot blowing to supplement the collectors.

A literature and field investigation was made by BCR to collect data on several types of water-spray dust collectors, including the Pease-Anthony cyclone and venturi collectors, as well as single and multiple-nozzle units. Installations were visted. The paper on stack sprays by Mr. Sam Radner of Chicago was also an important reference.

Simple stack sprays have been installed in various plants. Even though the installation cost is small and the maintenance and operating costs almost negligible, the stack spray has not become popular. Some former users of coal have changed to another fuel just to get away from the air pollution problem. In some cases they stopped using the stack-spray because of the fear that the stack would be damaged by the impingement of the water on the hot lining of the stack and possibly by corrosion due to the formation of sulfuric acid by the water and gases. On the other hand, practically every stack-spray that has been properly installed and operated has proved highly successful in eliminating the dust nuisance, and has caused no damage to the stack.

In the BCR laboratory in Columbus we have set up equipment in which we can simulate actual operating con-

ditions as they exist in the stacks of small plants. This installation is equivalent to that of a plant with a boiler rated from 75 hp to 100 hp capacity. In this project we will use the actual dust taken from the stacks and collectors of commercial plants and will have the means of controlling the amount of this dust entering the stack from the breeching.

Figure 1 shows part of the stack-spray equipment in the laboratory. In the background is the stack in which spray nozzles will be placed along the stack axis. Extending toward the front of the picture is the breeching, and in the foreground is the stoker-fired furnace. Under the breeching and directly behind the furnace is the pressure fan which will deliver dust-laden air up through an elbow and into the breeching where it will mix with the hot gases from the furnace and then flow on into the stack. The temperature of the resultant mixture of air and gases in the breeching can be controlled to a temperature that will correspond to that found in flue gases of industrial plants.

We will also duplicate the grain loading found in actual plants as we have positive control over the amount of dust being added to the air going into the pressure fan. This is done by means of a vibratory feeder mounted over the air-intake pipe on the fan. The feeder has a manual volume control as well as a rheostat-controlled electro-magnet on the feeder trough. The resultant

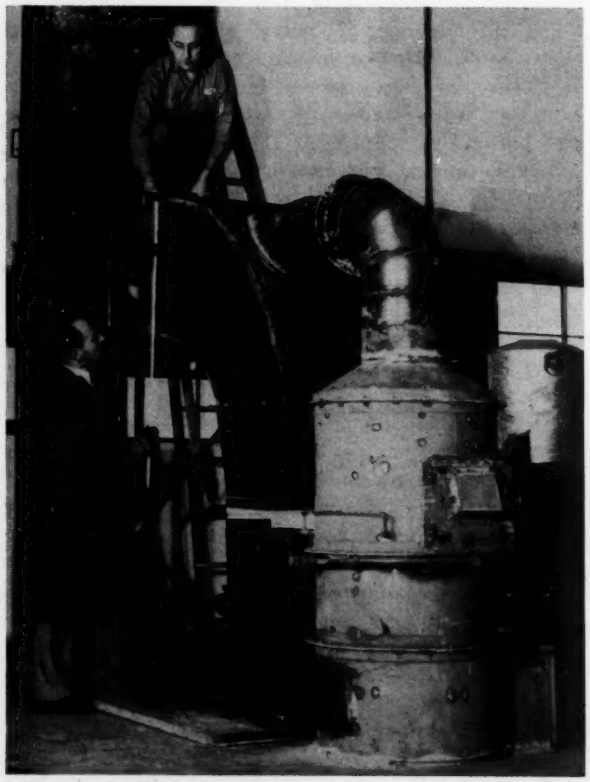

Fig. 1. Test apparatus for stack sprays.

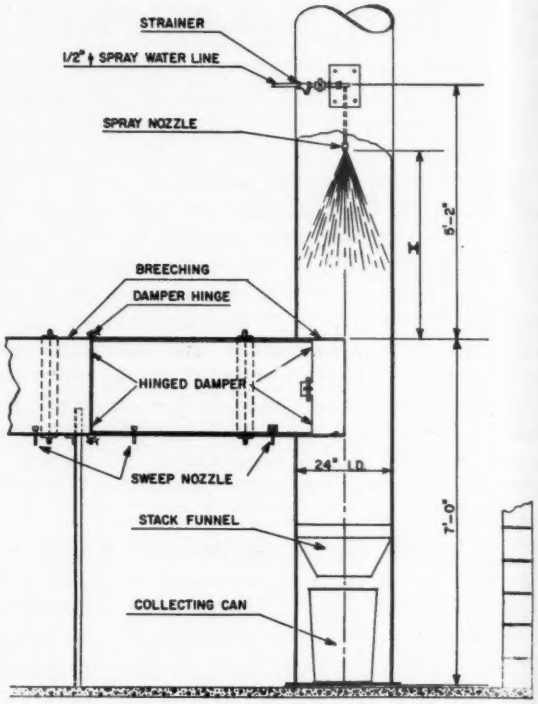

Fig. 2. Cross section showing location of spray nozzle.

volume of feed from certain control positions will be determined in advance of the actual test runs since it will be necessary to know the exact amount of dust used during each run in order to calculate the grain loading and the efficiency of collection. The dust and water collected in the base of the stack will be weighed and analyzed.

The water supply for the stack spray nozzle will come from a 60 gallon tank, a portion of which can be seen just to the right of the furnace in Figure 1. This tank is equipped with glass gages which will indicate the total gallons of water in the tank at any given time. A calibrated scale behind the gages indicates the amount of liquid by direct reading. Compressed air piped into the top of the tank and controlled by a regulator will maintain constant pressure in the tank and up to the spray nozzle at all times.

An instrument panel, not shown in the picture, has been installed to mount the gages, clocks, manometers, and valves which will be used to control flow rates of materials, indicate drafts at various points, temperatures, and the time each part of the process was used.

Figure 2 shows a side elevation and partial cutaway of the 24 inch stack and breeching as seen from the side opposite to that shown in Figure 1. This view shows where the spray-water line enters the stack in relation to the breeching. The distance from the spray nozzle to the top of the breeching is a variable. Within the breeching is shown the hinged damper or baffle which controls the direction of flow of the gases entering the stack.

In the bottom of the breeching are air-sweep nozzles which are used to move any dust that settles on the bottom of the breeching during a test run. This dust is swept out at the end of the run but before the spray is shut off.

Near the bottom of the stack is shown a funnel which collects the material coming down from the spray and directs it into a container which can be removed and its contents weighed and analyzed. The amount of dust collected by the can, when compared with the amount fed into the system during the run, indicates the efficiency of collection.

Instructions for installing and operating a spray type dust collector should be complete but easy to understand. The system should be so arranged that when the soot-blowing valve is opened the spray water valve automatically opens. The automatic feature can be included in the system at relatively low cost.

If this project proves successful, we plan to compile a bulletin which can be used by fuel and combustion engineers and coal salesmen to instruct their customers on how to eliminate much of the dust nuisance caused by soot blowing. Air pollution control officials will want to apply the results.

BCR is happy to announce that the Diamond Power Specialty Corporation of Lancaster, Ohio, is making an important contribution of funds and experience to the project. The Binks Manufacturing Company and the Spraying Systems Company have furnished nozzles and data on spray patterns.

Dust Emission from Boiler Furnaces

During 1953, a BCR sponsored project at Battelle Memorial Institute was completed with a series of tests on cinder emission from a small spreader-stoker-fired boiler. The maximum steaming capacity of the boiler shown in Figure 3 was 11,500 lb. per hr. actual evaporation. Coal was fired on a Coxe traveling grate with an Iron-Fireman pneumatic spreader stoker. A high efficiency dust collector trapped the cinders, which were reinjected to the combustion chamber.

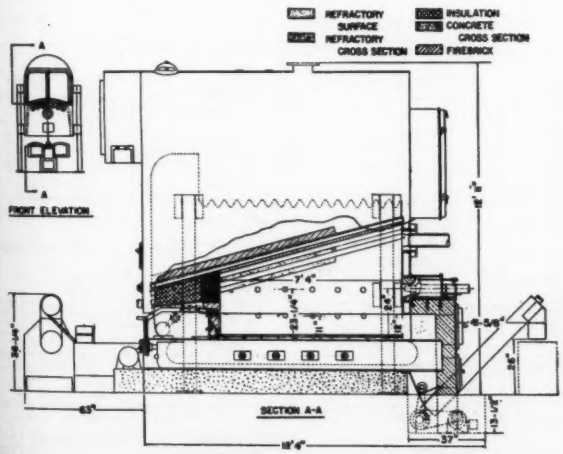

Fig. 3. Automatic steam generator.

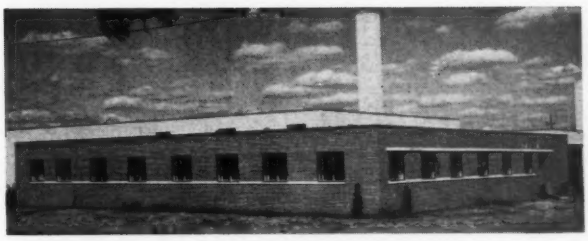

Fig. 4. BCR laboratory.

Overfire air jets were found to be effective in holding the smoke emission well below requirements, but they did not improve the combustion of the cinders. The effect on cinder emission of various lengths of refractory arches over the fuel bed was investigated, as was cinder reinjection. Studies were also made on coal distribution on the grate from a pneumatic stoker. More details and results of the work are to be given in a report for publication to be prepared by Battelle.

Dust Factors

The series of meetings with dust collector manufacturers during the last few years is being continued in an effort to improve and standardize the methods of measuring and reporting flue dust, and for predetermining the collectibility of dusts from small samples. General agreement is also being reached on the advisability of measuring terminal velocities of dust fractions, rather than micron sizes.

The ASME method for dust loadings, while accurate to within plus or minus 4.5 per cent, according to Holton and Schultz, is too expensive for routine purposes. The "null method" of sampling is one of several simpler methods under consideration. A simpler dust sampler would be a useful tool for air pollution control officials.

BCR is equipped to check the accuracy of sampling methods under conditions of measured gas and dust flow. A cooperative research program is being offered to dust-collector manufacturers and others who are interested in working together on the above subjects.

Electricoal Project

The emission of sulfur dioxide and fly ash from the chimneys of large coal-fired boilers has prompted an investigation at the BCR laboratory on the possibilities of flue gas cleaning and simultaneous heat recovery.

Chemical treatment of the flue gas to remove sulfur dioxide is being attempted to find an economical method. The process should also trap fine dust which now escapes the conventional dust collectors and precipitators. The study is in its early stages and results are not yet available.

BCR Laboratory

The experimental work now in progress and proposed for 1954 is being conducted in the new BCR Laboratory

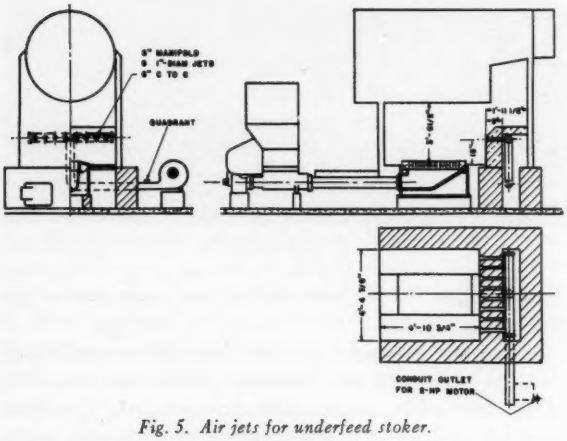

Fig. 5. Air jets for underfeed stoker.

in Columbus, Ohio, shown in Figure 4. Occupied on September 1, 1953, the two buildings provide 12,000 sq. ft. of floor area.

Work is also progressing on other projects, such as the development of stokers, an automatic steam generator, crop dryers, and the determination of coal and ash characteristics. Sponsors include BCR and private industries. Visitors are cordially welcomed at all times.

BCR Educational and Technical Service

An important part of BCR activities is the educational and technical information service available to coal users. The ultimate justification for research is the application of its results in the field. The presentation of technical papers, publication of engineering booklets, such as BCR Aids to Industry, and articles in the trade press, help in the dissemination of research information. However, nothing is as effective as the person-to-person discussion for the transmittal of new ideas. For this reason, BCR has made available a technical educational service to coal users which we call the BCR Combustion Conference program. Qualified engineers from the bituminous coal industry act as speakers to groups of engineers and other interested technical groups in important coal-using areas.

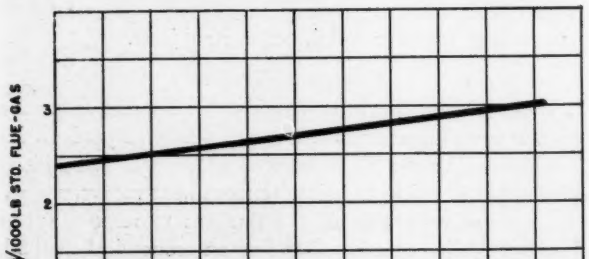

Fig. 7. Increase in flue dust emission with minus 28 mesh coal.

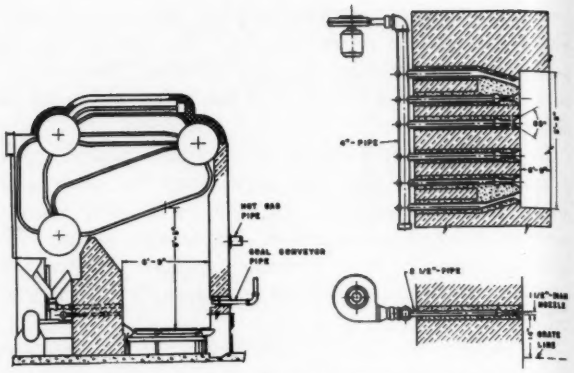

Fig. 6. Air jets for pneumatic spreader-stoker.

The talks are based on technical material prepared by BCR using the research information obtained in the laboratory and field.

Most of these efforts have been concerned with the more efficient, and cleaner, use of coal and should therefore be of direct interest to members of the Air Pollution Control Association. Three subjects are available for presentation, two of which are concerned directly with the control of smoke and flue dust. They are:

"The Use of Overfire Jets for Smoke Reduction"

"Reducing Flue-Dust Emission from Small Industrial Boiler Plants"

The first talk is based on the extensive research work undertaken by BCR and Battelle on the overfire jet, and most members of APCA are familiar with it. However, requests for presentation of this subject are still being received. Figures 5 and 6 show typical illustrations used in connection with this talk. Models of steam-air jets are also available and a simple demonstration may be used to show the principle of overfire air.

The talk on flue dust emission is a complete survey of the factors affecting it and the equipment at present

(Concluded on page 164)

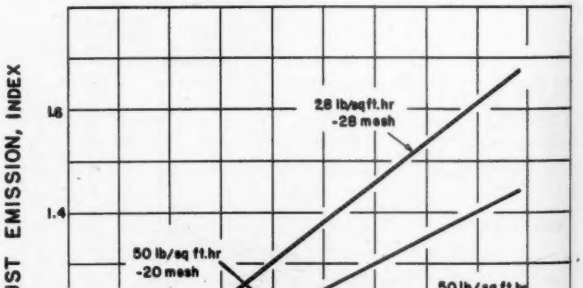

Fig. 8. Effect of coal fines on flue dust emission.

The Collection of Silica Fume with a Venturi Scrubber

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Battelle Memorial Institute
Columbus, Ohio

In the production of ferrosilicon in an electric-arc furnace, a certain portion of the silica rock charged is converted to silica fume. This material consists of extremely small particles whose sizes range from about 0.01 to 0.5 μ. The principal reaction inside a ferrosilicon furnace can be stated generally as follows:

$$Fe + SiO_2 + 2C \longrightarrow FeSi + 2CO.$$

However, several investigators[1-2] have postulated that the silica fume results from one or more side reactions which proceed to some extent to produce silicon monoxide (SiO):

$$(1)\quad SiO_2 + Si \longrightarrow 2SiO$$

$$(2)\quad \begin{cases} SiO_2 + 3C \longrightarrow SiC + 2CO \\ 2SiO_2 + SiC \longrightarrow 3SiO + CO \end{cases}$$

$$(3)\quad SiO_2 + C \longrightarrow SiO + CO$$

Silicon monoxide is more volatile than either Si or SiO_2 and is thought to evolve as a gas which, after striking the air above the furnace, immediately oxidizes and solidifies into minute spherical particles of silica. These small spherical particles, suspended in furnace gases pour, from the furnace as clouds of fume. The gases also carry with them coke, rock, and iron oxide dust whose particle-size range is considerably greater than that of the silica fume. The number of these larger particles, however, is small relative to the number of fume particles. Thus, the problem is one primarily of plume opacity.

Fig. 1 shows an electron micrograph of a silica-fume sample collected with a thermal precipitator over a ferrosilicon furnace. All particles in the sample were spherical and their diameters were within the range 0.01 to 0.5 μ.

Chemically the fume consists of from about 50 to almost 100% SiO_2, depending upon the grade of ferrosilicon being produced and other operating variables. It contains smaller quantities of iron, manganese, aluminum, magnesium, and carbon. The color of the collected material is from gray to off-white. The bulk density is extremely low—in the order of 11 to 12 lbs./ft.^{3}

In a program sponsored jointly by the Keokuk Electro-Metals Company and the Tennessee Products and Chemical Corporation, the Fuels and Air Pollution Division of Battelle Memorial Institute was asked to make a thorough study of the fume-emission problem from ferrosilicon furnaces. One of the first phases of this program was to study representative types of dust-collection equipment which would be most likely to collect the fume at reasonably high efficiencies. The field was narrowed down to the following three basic types:

(1) High energy scrubbing
(2) Electrostatic precipitation
(3) Filtration with a baghouse

This paper reports the results obtained with a pilot-scale venturi scrubber, the first of these units to be tested. Equipment of this type has been widely used for the collection of submicron particles.[3-4-5] Studies with the scrubber were conducted in December of 1953 at the Keokuk Electro-Metals Company in Keokuk, Iowa. The purpose of this study was to measure the weight efficiency of collection of furnace fumes with the venturi scrubber, and make an estimate of costs involved in operating a full-scale scrubber unit.

1. Zintl, E. and others, "Silicon Monoxide," *Z. anorg. u. allgem. Chem., 245*, 1-7 (1940).
2. Zapffe, C. A., and Sims, C. E., "Silicon Monoxide," *The Iron Age* (January 22 and 29, 1942).
3. Ekinan, F. O., and Johnstone, H. F., "Collection of Aerosols in a Venturi Scrubber," *Ind. Eng. Chem., 43* (6), 1358 (1951).
4. Jones, W. P., "Development of the Venturi Scrubber," *Ind. Eng. Chem., 41* (11), 2424 (1949).
5. Johnstone, H .F., "New Engineering Developments in the Control of Air Pollution," *Chemistry in Canada,* (October, 1952).

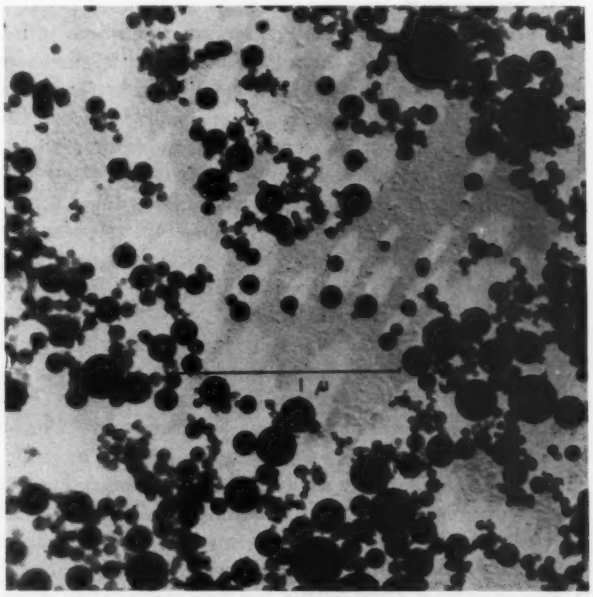
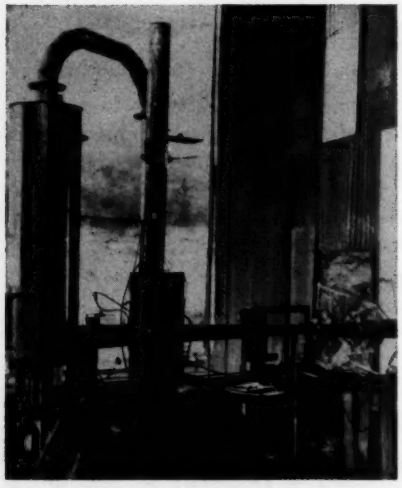


Fig. 1. Electron micrograph of silica-fume sample collected with a thermal precipitator.

Fig. 2. A photograph of the venturi-scrubber installation at the Keokuk Electro-metals Company.



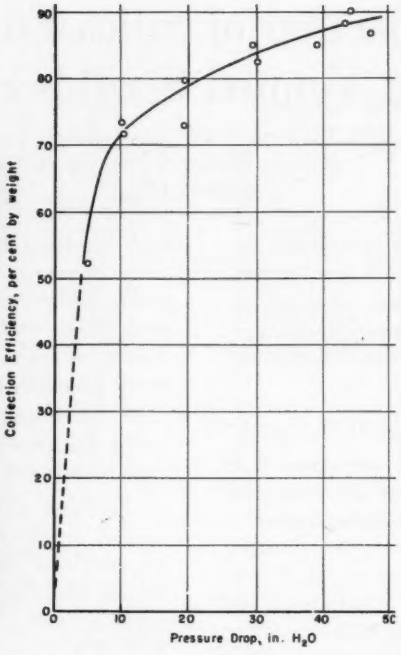
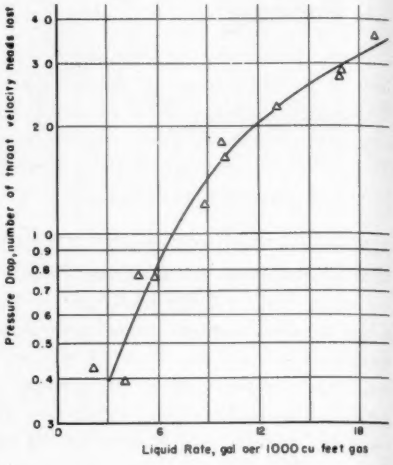


Fig. 3. Venturi-scrubber efficiency curve for silica-fume removal.

Fig. 4. Pressure loss in venturi scrubber.



Equipment and Procedure

A portable venturi scrubber supplied by the Chemical Construction Corporation was used in this study. This unit, which is shown in Fig. 2, consisted of the following components:

(1) A venturi nozzle having a throat diameter of 2.5 in.
(2) A cylindrical separator chamber.
(3) A blower rated at approximately 500 cfm. at 50 in. static pressure.

In operation, the fume-laden gases were pulled through the venturi nozzle where low pressure water was introduced at the throat through three 0.238-in.-diameter nozzles. On contacting the high velocity gas stream, the water "curtain" was shattered into small droplets. On coming in contact with water droplets, the fume particles were collected. The dust-laden water droplets passed into a cylindrical separator chamber where centrifugal action separated the "contaminated" water droplets from the gas stream. The fume-laden wash water was sent to a drain. The cleaned gases passed through the blower and were discharged to the atmosphere.

The venturi scrubber was connected by approximately 40 ft. of 8-in.-diameter sheet-steel duct to a hood placed 16 ft. above the center of the ferrosilicon furnace. This furnace, rated at 7500 kw., was producing 16% ferrosilicon. Inlet-sampling ports were located in a 10 ft. section of 6 in. diameter smooth steel pipe connecting the duct with the scrubber. An outlet-sampling port was located in the blower discharge line so that the saturated gases in passing through the blower would be heated above their dew point. This insured that condensation would not normally occur in the outlet samplers. In both sampling ports, temperature, humidity, and pressure-measuring devices were placed.

Samples for grain-loading and particle-size-distribution studies were taken simultaneously at both the scrubber inlet- and outlet-sampling ports. Samples for grain loading were collected on filter pads consisting of approximately 1.4 μ diameter glass fibers (Owens-Corning Fiber Glass PF-105). Particle-size-distribution samples were obtained with an oscillating thermal precipitator in which the oscillation of the collector plate insured a uniform sample.[6] Temperature, pressure, and humidity measurements were taken simultaneously with grain-loading and thermal-precipitator samples. The pressure drop across the venturi nozzle, the water-injection rate, and the water inlet and outlet temperatures were also measured.

TABLE I

Summary Table of Venturi Scrubber Tests

Inlet Fume Loading, mg./cu.ft.[a]	Throat Velocity, ft./sec.	Liquid Rate, gal./1000 cu. ft.	Pressure Drop, in. water	Collection Efficiency %
15.1	291	16.9	43.3	88.2
22.3	363	9.6	39.0	85.2
13.1	269	13.0	29.6	85.1
12.0	327	9.7	30.1	82.7
15.2	299	8.7	19.3	79.7
17.2	379	4.9	19.3	72.7
11.9	278	5 6	10.1	71.7
41.5	381	2.1	10.0	73.3
38.4	276	19.0	47.0	86.9
33.3	281	4.0	5.0	52.0
24.5	314	16.7	44.0	90.4

[a]Based on air at 60°F. and 14.7 psia.

6. Stokinger, H. E., and Laskin, S., "Air Pollution and the Particle-Size Toxicity Problem-II", *Nucleonics*, 6, (3), 15 (1950).

In operation, the venturi scrubber was started and allowed to come to equilibrium at some predetermined pressure drop and water-injection rate. Four-point pitot-tube traverses were then made in the inlet- and outlet-sampling ports. The points of average velocities within the ducts were determined and the sampling probes positioned there. The air rate through the samplers was regulated so that the flow of fume-laden air entering the sampling probe was isokinetic. Samples were taken for periods of from 10 to 20 minutes after which the glass filter pads were dried and weighed. Thermal-precipitator samples were examined under the electron microscope and particle-size distributions were determined by statistically counting the numbers of particles in a representative area of the sample. Samples of fume were also taken from the glass-fiber filter pads and examined under the optical microscope.

Experimental Data

The results obtained on grain-loading studies with the venturi scrubber are listed in Table I. During these tests inlet fume loadings varied between 11.9 and 41.5 mg./ft.^{3}, depending upon variations in furnace operation during the test runs. Theoretically, it was possible in the venturi scrubber to obtain a given pressure drop across the venturi nozzle with an infinite number of combinations of air-flow and water-injection rates. Whenever possible, at least two combinations of these variables were used to obtain a given pressure drop. Collection efficiencies were found to lie between 52.0 and 90.4%. There was a good correlation between collection efficiency and pressure drop (shown by the smooth curve in Fig. 3). The collection efficiency was found to be virtually independent of inlet grain loading, throat velocity, and liquid rate at a given pressure drop. It was also apparent that the rate of increase of efficiency versus pressure drop began to fall off after pressure drops exceeded about 20 in. of water.

The pressure drop, expressed in number of throat velocity heads[7], was found to be a function of liquid rate expressed as gal./1000 cu. ft. of gas. The data shown in Fig. 4 checked well with other pressure-drop data available on venturi scrubbers.[8]

Typical particle-size distributions of the submicron portion of the fume sample taken with thermal precipitators, are shown in Fig. 5, 6, and 7. These show inlet and outlet particle-size distributions at venturi pressure drops of 5.0, 19.0, and 44.0 in. water gage, respectively. The range of particle diameters was 0.01 to 0.4 μ. It is evident from the distribution curves that in the size range studied there was no selective removal of particles of any one size. This occurred at each of the pressure drops studied. Although it may seem unusual that there was no selective collection of the larger particles in this size class, identical results were reported some years ago in tests of a venturi scrubber operated at 12 to 15 in. water gage, on fume from a silicon electric furnace.[9] These results indicate that diffusional processes may enter into the collection of submicron particles.[10]

Samples of fume taken from the glass filter pads used for grain-loading studies are shown in Fig. 8, 9, and 10. These show light micrographs at a magnification of 1500 of inlet and outlet samples taken at pressure drops of

TABLE II

Estimated Operating Expenses For A Venturi Scrubber

Basis:	80,000 cfm. of furnace gases	Capital Investment, dollars[a]	$82,500
	8000 hr. of operation per yr.	Capital Investment, dollars per cfm.	1.031
	Yearly Operating Expenses, dollars per cfm.		
Fixed Charges, 10%/yr.			$0.103
Power Costs, 1.5 cents/kwhr.[b]			0.579
Water Costs, 2.0 cents/1000 gal.			0.054
Labor Costs, $1.75/hr.			0.015
Total Operating Expenses			0.751

(a) Capital investment taken as 1.5 times equipment cost.
(b) Combined motor and blower efficiency taken as 63%.

7. Lapple, C. E., et al., "Fluid and Particle Dynamics," University of Delaware Press (March, 1951).
8. Lapple, C. E., and Kamack, H. J., "Performance of Wet Dust Scrubbers," presented at Am. Inst. Chem. Engrs. Meeting, St. Louis (December 16, 1953).
9. Anthony, A. W., "Two Methods of Wet Scrubbing of Gases for Reduction of Atmospheric Pollution," presented at Forty-First Annual Meeting of SPAA, New York (June 7-11, 1948).
10. Johnstone, H. F., and Roberts, M. H., "Deposition of Aerosol Particles From Moving Gas Stream," *Ind. Eng. Chem., 41,* 2417-2423 (November, 1949).

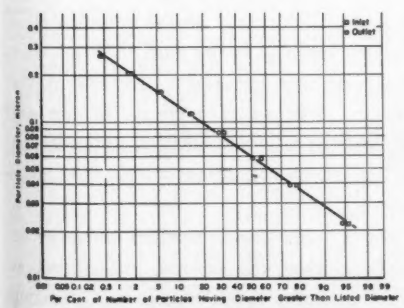


Fig. 5. Particle-Size distribution of inlet and outlet samples taken at Δp=5.0 inches water.

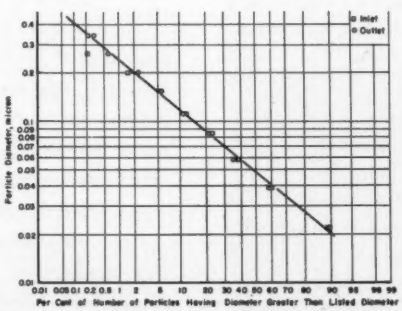


Fig. 6. Particle-Size distribution of inlet and outlet samples taken at Δp=19.0 inches water.

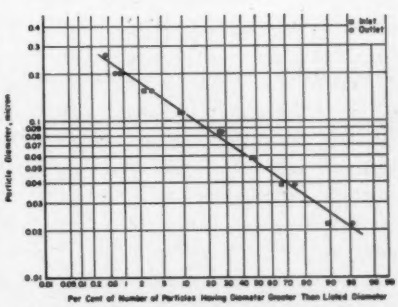


Fig. 7. Particle-Size distribution of inlet and outlet samples taken at Δp=44.0 inches water.

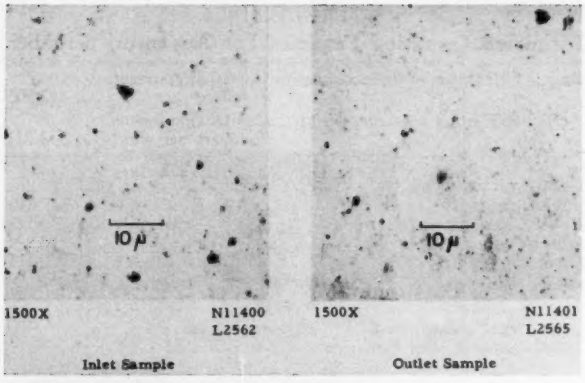


Fig. 8. Light micrographs of samples taken at a pressure drop of 5.0 inches of water and collection efficiency of 52.0 per cent.

5.0, 10.0, and 44.0 in. water, respectively. The presence of the larger particles in ferrosilicon-furnace gases is indicated. These figures clearly show the effect of venturi pressure drop on the effectiveness of removal of these larger particles. With increasing pressure drop, the relative number of large particles in the outlet samples decreased markedly. The greatest difference in size range between inlet and outlet samples was noted in the run made at 44 in. of water gage. This effect was confirmed by the appearance of the outlet stack of the scrubber. There was a noticeable decrease in the opacity of the exit gases with an increase in pressure drop.

Costs Of A Commercial Venturi Scrubber

An estimate of the capital investment costs and operating expenses for a typical commercial venturi scrubber has been made. A summary is given in Table II. A scrubber of 80,000 cfm. capacity operating at a static pressure of 37 in. water gage was assumed. The figure for required scrubber capacity was obtained from measurements of CO_2 concentration at the sampling hood. An operating year of 8,000 hr. was selected.

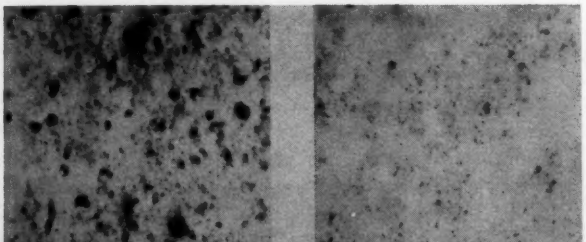


Fig. 9. Light micrographs of samples taken at a pressure drop of 10.0 inches of water and collection efficiency of 73.3 per cent.

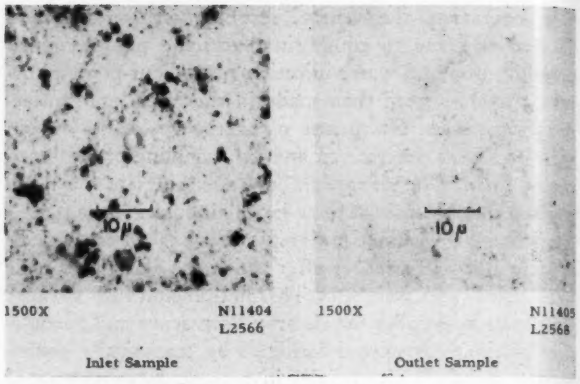


Fig. 10. Light micrographs of samples taken at a pressure drop of 44.0 inches of water and collection efficiency of 90.4 per cent.

The capital investment was estimated to be $1.031/cfm. This is a low capital investment relative to other collector types suitable for such application, and reflects the intrinsic simplicity of a venturi scrubber. Operating expenses, on the other hand, are high, as would be expected from the high power input to a unit of this size. These cost figures indicate that it might cost as much as $60,000/yr. to handle all of the gases from a single 7500 kw. furnace. This cost would be very high for the small operator and indicates the need for drastic reduction of the volume of furnace gases by suitable hooding or enclosure.

Water costs, based on an estimated water requirement of 450 gpm., were found to be negligible. Labor costs were based on two man-hours per day. It was our experience in operating the venturi scrubber that it was necessary only to turn on the blower and open the water-injection valve. Once started, little or no attention was required since the operation of the unit was extremely stable.

Conclusions

These studies have shown that silica fume can be collected at relatively high weight efficiencies in a venturi scrubber, but only at the expense of substantial quantities of power needed to create the pressure drop through the unit. Efficiencies between 52 and 90% were obtained over a pressure-drop range of 5 to 47 in. of water gage.

Particle-size studies of inlet and outlet samples indicate that the relatively large particles (up to 7 μ) were collected selectively with the greatest collection at the highest pressure drops. The fume particles in the size range between 0.01 and 0.4 μ were collected uniformly at all pressure drops; i. e., no one size class within this range was collected selectively.

Cost estimates for a commercial venturi scrubber in this application showed that the capital investment as compared with other collector types was low. Operating expenses, on the other hand, were high and reflected the high power requirements.

The Magnitude of Errors in Stack Dust Sampling*

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Industrial Hygiene Foundation
Pittsburgh, Pa.

The assembly of various elements that may be employed in the collection of a representative sample of dust from a stream of dust-laden gases is a subject that has been rather completely discussed in various publications[1-2-3-4-5] and such details will therefore not be treated exhaustively in this paper. The assembly employed in a particular case usually represents the personal preferences and prejudices of the particular worker. We have some preferences of our own and will describe the important ones in the preliminary part of this presentation before setting forth the results of studies on the magnitude of errors inherent in the conventional sampling procedures.

As is well known, the primary problem in such dust sampling is to avoid selective sampling of particular particle sizes due to inertial effects. This is accomplished by aspirating through a sampling nozzle, a sample of the dust-laden gas at the same velocity as that prevailing in the main gas stream.

Gas sampling falls naturally into two principle classes: small volume sampling where the sampling rate amounts to ½ to 2 cfm., and large volume gas sampling involving rates from 10 to 40 cfm. The latter is usually selected where it is desirable to acquire a liberal sample of dust for subsequent laboratory studies. We shall confine the present discussion to the small volume sampling category.

We sub-divide small volume sampling equipment into two main types: that employing an exterior filter, i.e., one with the filter disposed outside the duct or stack and a sampling tube connecting it to the nozzle proper; the other employing an integral filter.

Exterior Filter Assembly

The assembly employing an exterior filter is frequently justified in particular circumstances but in our experience its disadvantages are important.

Sampling Tube Hazards

Deposits of dust between the nozzle and the filter occur in varying degree and may be a serious source of error unless particular precautions are taken to remove them quantitatively at the end of each test. The magnitude of the error will be dependent upon the total quantity of dust that comprises the sample. Our experience has indicated that dry brushing of the tube interior may be completely inadequate to dislodge all of the dust. We observed in one instance (sampling flue gases in coal stoker firing) a remaining deposit of dust following vigorous dry brushing amounting to 150 mg. in a 6 ft. long, stainless steel sampling tube, ⅜ in. in diameter. Since the total weight of material collected in the filter was usually less than 500 mg., this tube deposit represented a major source of error. The only certain cleaning procedure involves washing with water in conjunction with a brush.

We have also experienced serious error from corrosion of the interior surface of a stainless steel tube due to the action of sulfurous gases and moisture condensation. Thus, it is imperative to avoid any condensation or moisture within the tube even though it be constructed of stainless steel. We have successfully used glass combustion tubing to avoid these difficulties. A blunt bevel can be ground on one end of the tubing following which an elbow is formed by bending, a simple operation for glass blowers. The tubing is extremely rugged and will withstand an amazing amount of rough usage.

Integral Nozzle and Filter

The errors due to losses in the sampling tube suggest enormous manipulative advantages to an arrangement in which the dust filter element is disposed immediately adjacent to the nozzle. The usual conditions of high stack gas temperature dictate the necessity for a filter material and housing that can withstand all temperatures which would reasonably be expected. The best in our experience is the alundum thimble filter, illustrated in Fig. 1 and 2. These thimbles are available in medium or coarse porosities and two common sizes 34 x 100 mm. and 45 x 127 mm. They are resistant to acid gas, can be subjected to temperatures of over 1000°F. and can be weighed with a high degree of accuracy. The alundum thimble does, how-

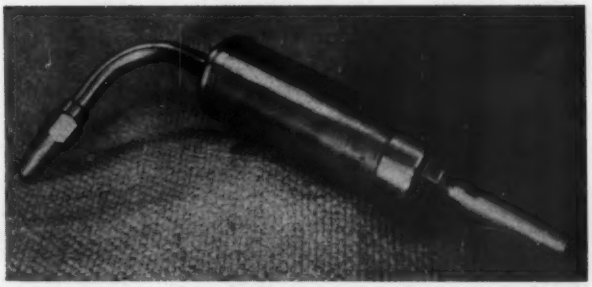

Fig. 1. Alundum Thimble Filter Holder Integral with Nozzle.

*Presented at the Semi-Annual Meeting of the American Society of Mechanical Engineers, June 22, 1954, Pittsburgh, Pa.

1. Hardie, P. H., "Resume of Methods for Measuring Flue Dust," *Trans. A.S.M.E.*, 59:355 (1937).
2. *Test Code for Dust Separating Apparatus,* Amer. Soc. of Mech. Engrs., *Test Code 21* (1941).
3. "Methods for Determination of Velocity, Volume, Dust and Mist Content of Gases," *Bulletin WP-50,* Western Precipitation Corp.
4. Arbogast, A. H., "The Quantitative Determination of Dust in Gas." *Iron & Steel Engineer,* Oct. 1948.
5. Holton, W. C. and Schulz, E. J., "Some Notes on Dust Sampling Equipment and Technique." *Trans. Amer. Soc. Mech. Engrs.* (Oct. 1953).

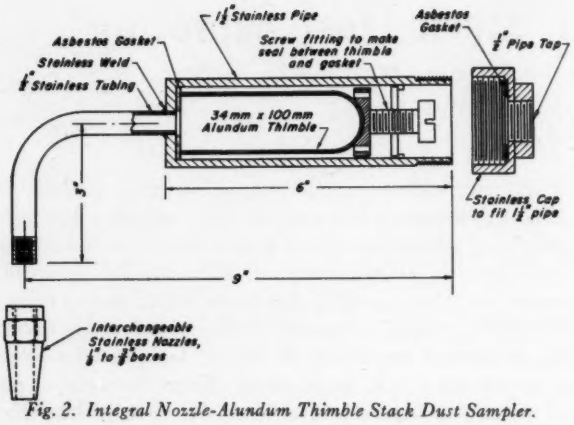

Fig. 2. Integral Nozzle-Alundum Thimble Stack Dust Sampler.

ever, have one important drawback, and that is its extremely high resistance to air flow.

Thimble Lining

We have succeeded in greatly reducing the resistance of this filter by the following technique. Using the coarse 34 x 100 mm. thimble, an especially fine diameter fiber spun glass (fibers approximately 1.5 μ in diameter) is applied as a lining to the inside wall by wrapping a suitable quantity of wool around a ¾ in. rod so that a tight pack is obtained when rod and wool are inserted into the thimble. The rod is then withdrawn (Fig. 3). The glass wool lining not only improves the resistance characteristics of the filter, but in preventing deposits of dust on the walls of the tube enables it to be used many times over.

The results of comparative tests for various types of fumes and dust showing the relative resistance to air flow are given in Table I. All resistance figures are reduced to a unit gas flow rate per unit area of filter and unit weight of dust.

The table indicates enormous reductions in pressure drop due to the simple addition of the glass wool liner.

Nozzle Design

Establishment of isokinetic velocity at the nozzle is greatly facilitated by the well-known "null" type nozzle which incorporates hollow chambers surrounding the nozzle proper with static pressure tubes communicating

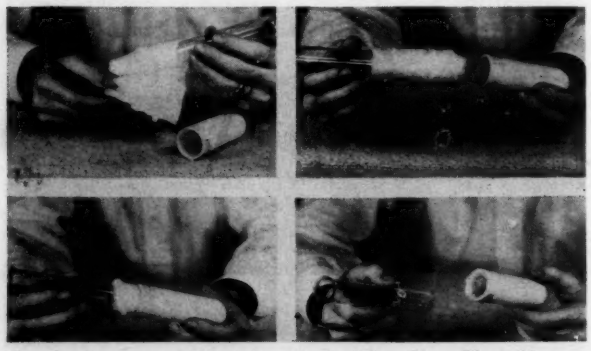

Fig. 3. Sequence of Operations in Applying Glass Wool Liner to Alundum Thimble Filter.

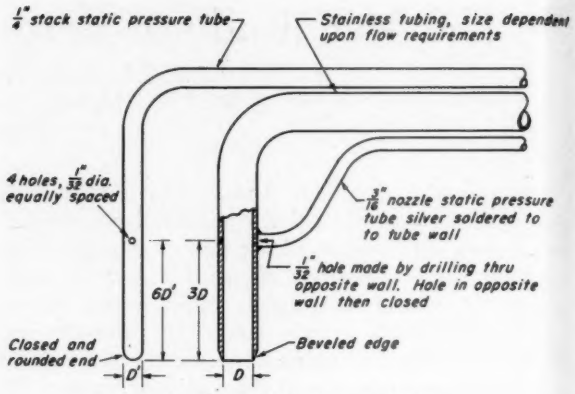
¼" stack static pressure tube
Stainless tubing, size dependent upon flow requirements
4 holes, 1/32" dia. equally spaced
3/16" nozzle static pressure tube silver soldered to to tube wall
1/32" hole made by drilling thru opposite wall. Hole in opposite wall then closed
6D'
3D
Closed and rounded end
Beveled edge
D'
D

Fig. 4. Simplified "null" nozzle design.

respectively with the sampling tube interior and with its exterior, i. e., the surrounding space through which the main stream of gases is passing. This form of nozzle suffers the disadvantage in that it requires special fabrication. Prior to the developments which will be presented in a separate paper[6], we explored the matter of simpler "null" type nozzle design and in particular the form illustrated in Fig. 4. While slightly less convenient due to the need for an independent static tube such as is provided by half of a pitot tube, it is immensely simpler to fabricate. We demonstrated that a single static hole in the sampling nozzle is adequate to register the interior pressure. The static connection is most readily fabricated by welding a 3/16 in. stainless steel tube to a spot on the nozzle wall about 3 diameters distant from the opening, such welding being done before drilling the static hole itself. Then a temporary access hole is drilled in the wall at a point opposite the static tube connection to effect communication through the nozzle interior to the opposite wall where the static hole is then drilled to effect the desired connection with the interior of the static tube. The access hole can then be closed.

Errors in Null Nozzle

A series of tests have been made to determine the mag-

TABLE I

Resistance Characteristics of Alundum Thimbles (With and Without a Fiberglas[a] Lining)

Filter Packing	Dust Collected	In. Water at 1 fpm.		
		Bare Thimble	Thimble +1 gm. dust	Total Resis.
None	MgO fume	2	11	13
Fiberglas	MgO fume	2	2	4
None	Boiler plant dust	2	30	32
Fiberglas	Boiler plant dust	2	6	8
None	Welding fume	2	150	152
Fiberglas	Welding fume	2	7	9

[a]Owens-Corning "A" Fiber Fiberglas (1.5 μ diameter)

6. Haines, G. F. Jr. and Hemeon, W. C. L., "A New Method for Stack Dust Sampling." Presented at the Semi-Annual Meeting of the ASME, Pittsburgh, Pa., June 22, 1954.

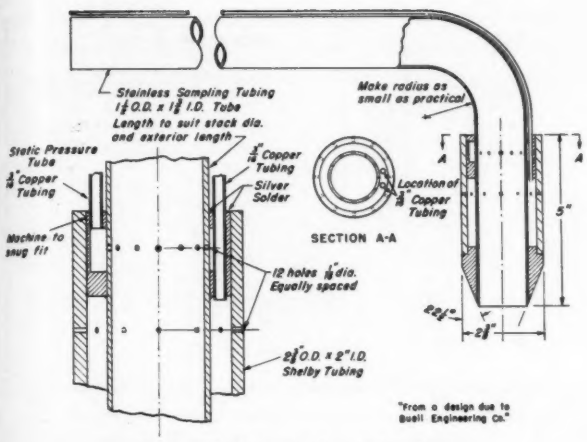

Fig. 5. "Null" nozzle of special design.

nitude of error resulting from extremely small departures from the zero pressure using the "null" nozzle. A 1⅜ in. I.D. stainless "null" nozzle with a piezometer ring, Fig. 5, and a ⅜ in. I.D. stainless "null" nozzle with a single static connection 3 diameters from the entrance, Fig. 4, were placed in a gas stream of known velocity. The nozzle velocity was then adjusted to various values differing from that of the gas stream and the corresponding departures from zero pressure observed.

The results are set forth in Fig. 6 and show that in low velocity streams significant sampling errors may result from small departures from "null" pressure. For example, in a duct with a gas velocity of 1000 fpm., a 40% sampling error may result from an 0.05 in. departure from "null". For a gas velocity of 3000 fpm., the same departure from "null" would result in only a 3% sampling error.

In a steady flow gas stream, static pressure differentials are quite easily held to within ± 0.01 or 0.02 in. of water on a draft gage. However, steady conditions frequently do not exist and reading errors of ± 0.05 in. of water may occur. Under these conditions the use of the "null" nozzle in low velocity streams is not reliable and is useful only as a rough means of adjusting to approximate isokinetic conditions.

TABLE II

Effect of Nozzle Size in the Collection of Coarse and Fine Dust Particles

Nozzle Size in., I.D.	Ratio = Actual Concentration / True Concentration
Coarse Particles (420 - 500 μ)	
1/8	.78 - .80
1/4	.84 - .90
3/8	1.0
Fine Particles (5 - 25 μ)	
1/8	1.0 - 1.04
1/4	1.0 - 1.03
3/8	1.0

Effect of Nozzle Size

Some study was made of the limitations as to minimum size of the sampling nozzle, data that was needed in connection with the development reported in a separate paper. These tests were made by comparing the concentrations collected by ⅛ and ¼ in. nozzles with that collected by a ⅜ in. nozzle. The effect of nozzle size in the collection of a fine and a coarse dust is shown in Table II.

Errors in Departure from Isokinetic Velocities

Since Hardie's review of this subject[1], some additional studies have been reported[7-8] on the magnitude of errors due to varying degrees of departure from isokinetic sampling conditions. In a desire to enlarge the field of knowledge in this respect, we undertook to investigate this question more fully, using the apparatus partially illustrated in Fig. 7.

1. See footnote (1) page 159.
7. Anderson, E., "On The Quantitative Determination of Industrial Gas Dispersoids." *Trans. A.I.Ch.E.*, pp. 589-601 (1938).
8. Fitton, A. and Sayles, C. P., "The Collection of a Representative Flue-Dust Sample." *Engineering*, Vol. 173, pp. 229-230 Feb. 22, 1952; pp. 261-263, Feb. 29, 1952.

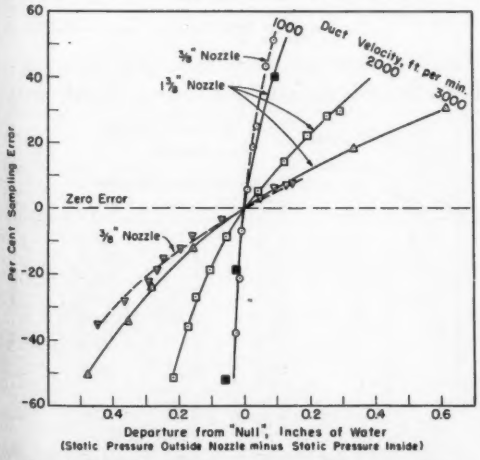

Fig. 6. Sampling Errors Due to Departures From "Null" Condition.

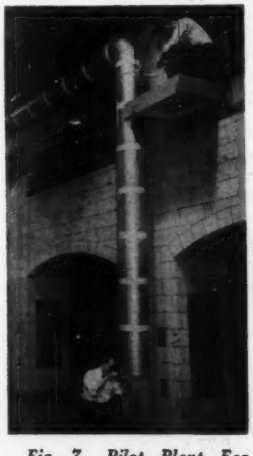

Fig. 7. Pilot Plant For Stack Dust Sampling Studies.

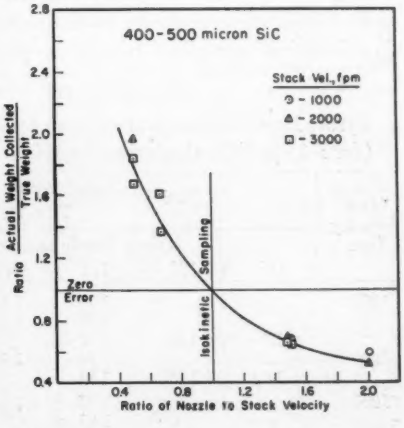

Fig. 8. Errors Due to Departures From Isokinetic Sampling (calculation based on nozzle velocity).

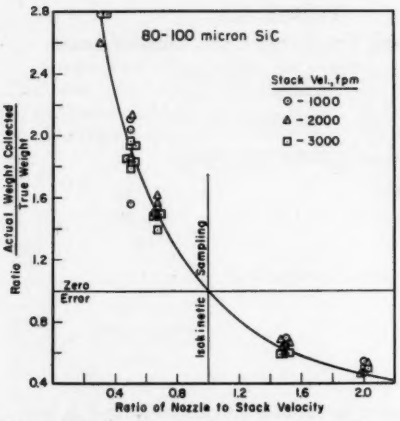

Fig. 9. Errors Due to Departures From Isokinetic Sampling (calculation based on nozzle velocity).

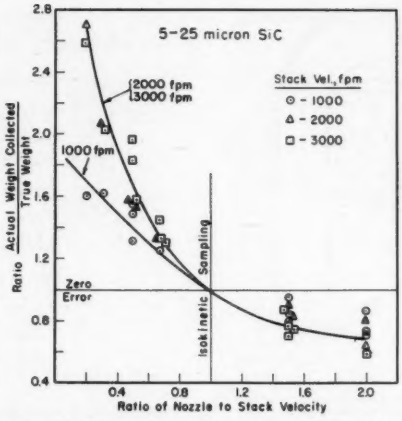

Fig. 10. Errors Due to Departures From Isokinetic Sampling (calculation based on nozzle velocity).

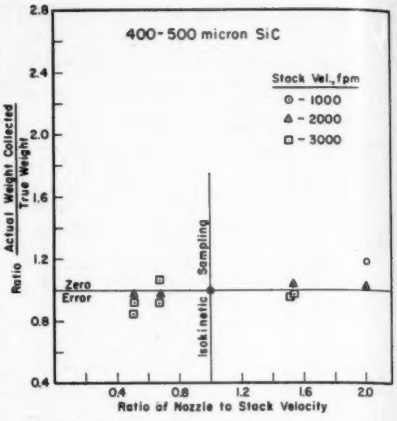

Fig. 11. Errors Due to Departures From Isokinetic Sampling (calculation based on stack velocity).

The duct system, 14 in. in diameter, has an air flow capacity of up to 4000 cfm. Dust of known particle size, using commercially available sized grains of silicon carbide, was injected at the duct entrance and simultaneous samples were taken at the top of a vertical run, 10 diameters distant, in an area of the cross section that had been previously explored in detail for uniformity. The results of these studies are tabulated in Tables III, IV, and V and illustrated graphically in Fig. 8, 9, and 10. The steepness of the curves is directly related to the inertial properties of the dust particles and they illustrate strikingly that a deficient nozzle velocity results in a greater error than an excessive nozzle velocity.

Where the nozzle velocity ranges from two-thirds of isokinetic velocity to two times that value, the extreme potential error amounts to from 40 to 60%.

The finer dust (5 - 25 μ) is somewhat less sensitive to departures from isokinetic velocity as would be expected, especially with excess nozzle velocity.

Nozzle Impaction Phenomena

In processing the data from one of these earlier controlled runs, we were struck by the observation that among five identical sampling tubes, sampling the dusty gas stream simultaneously at rates of flow whose extremes were within the ratio of 4 to 1, practically the same weights of dust were collected in each case. The data given in Table VI are typical.

This striking fact indicated that within the range of these particular test conditions, the velocity into the nozzle had no important bearing on the quantity of dust collected. This could only mean that the inertia of these particles, as determined by the velocity of the gases as they approached the nozzle opening, determined the quantity of dust entering the sampling tube. That is, entrance of the particles into the sampling nozzle is due to a process of "impaction". It seemed clear, and was subsequently borne out in later experiments detailed below, that there must be some approach velocity (for a given particle size) below which the efficiency of impaction would drop off.

However, these observations suggested the value of a different method for computing the results of such tests, wherein the volume of the gas sample is defined not as the quantity entering the nozzle but the quantity *approaching*

TABLE III

Errors Due To Departures From Isokinetic Sampling (for 5-25 μ SiC-calculations based on *nozzle* velocity)

Stack Velocity fpm.	Ratio = Actual Weight Collected / True Weight					
	Ratio of Nozzle to Stack Velocity					
	1/5	1/3	1/2	2/3	1 1/2	2
1000	.....	.....	1.49	1.30	0.95	0.86
	.....	.....	1.55	1.25	0.84	0.73
	1.6	1.62	1.31	.....	0.80	0.71
2000	.....	.....	1.56	1.33	0.89	0.63
	2.69	2.05	1.53	.....	0.82	0.80
3000	.....	.....	1.97	1.45	0.86	.....
			1.83			
	.....	.....	.....	1.33	0.77	.....
	.....	.....	.....	1.33	0.75	.....
	2.59	2.06	1.58	.....	0.70	0.59

TABLE IV

Errors Due To Departures From Isokinetic Sampling (for 80-100 μ SiC-calculations based on *nozzle* velocity)

Stack Velocity fpm.	Ratio = Actual Weight Collected / True Weight					
	Ratio of Nozzle to Stack Velocity					
	1/5	1/3	1/2	2/3	1 1/2	2
1000	.....	.....	2.10	1.52	0.64	0.50
	.....	.....	1.55	1.48	0.69	0.54
	4.17	2.83	2.03	.....	0.58	0.47
2000	.....	.....	2.12	1.61	0.65	0.40
	.....	.....	1.82	1.56	0.68	0.52
	3.92	2.58	1.85	.....	0.63	0.45
3000	.....	.....	1.83	1.39	0.59	.....
			1.93			
	.....	.....	1.96	1.49	0.58	.....
			1.88			
	.....	.....	.....	1.50	0.60	.....
	.....	.....	1.82	1.48	0.65	.....
	4.24	2.85	1.93	.....	0.63	0.49

TABLE V

Errors Due To Departures From Isokinetic Sampling (for 400-500 μ SiC-calculations based on *nozzle* velocity)

Stack Velocity fpm.	Ratio = Actual Weight Collected / True Weight: Ratio of Nozzle to Stack Velocity 1/2	2/3	1 1/2	2
1000	(1.16)[a]	(0.96)[a]	0.68	0.59
2000	1.97	1.45	0.68	0.51
3000	1.84	1.61	0.63	.....
	1.67	1.37	0.65	.....

[a]Particle settling velocity approaches nozzle velocity

TABLE VI

Weight of Coarse Dust (80-100 μ Silicon Carbide) Collected in Five Nozzles Sampling Simultaneously at Varying Velocities

Duct Velocity	Milligrams of Material Collected — Ratio, Sampling Nozzle Velocity: Duct Velocity 1/2	2/3	1	1 1/2	2
1000	358	345	341	329	341
2000	420	480	402	472	478
3000	329	316	340	299	.....

TABLE VII

Errors Due To Departures From Isokinetic Sampling (for 5-25 μ SiC-calculations based on *stack* velocity)

Stack Velocity fpm.	Ratio = Actual Weight Collected / True Weight: Ratio of Nozzle to Stack Velocity 1/5	1/3	1/2	2/3	1 1/2	2
1000	.....	.....	0.75	0.87	1.42	1.72
	.....	.....	0.77	0.83	1.26	1.46
	0.32	0.54	0.65	.....	1.20	1.42
2000	.....	.....	0.78	0.89	1.33	1.26
	0.54	0.68	0.76	.....	1.23	1.60
3000	.....	.....	0.99	0.97	1.29	.....
			0.92			
	.....	.....	.....	0.92	1.15	.....
	.....	.....	.....	0.92	1.13	.....
	0.52	0.68	0.79	.....	1.05	1.18

TABLE VIII

Errors Due To Departures From Isokinetic Sampling (for 80-100 μ SiC-calculations based on *stack* velocity)

Stack Velocity fpm.	Ratio = Actual Weight Collected / True Weight: Ratio of Nozzle to Stack Velocity 1/5	1/3	1/2	2/3	1 1/2	2
1000	.....	.....	1.05	1.02	0.96	1.00
	.....	.....	0.78	0.99	1.03	1.08
	0.84	0.94	1.01	.....	0.87	0.94
2000	.....	.....	1.06	1.07	0.97	0.80
	.....	.....	0.91	1.04	1.02	1.04
	0.79	0.86	0.93	.....	0.95	0.90
3000	.....	.....	0.92	0.93	0.89	.....
			0.96			
	.....	.....	0.98	0.99	0.87	.....
			0.94			
	.....	.....	.....	1.00	0.90	.....
	.....	.....	0.91	0.99	0.97	.....
	0.85	0.95	0.96	.....	0.95	0.98

it, regardless of whether a portion of this stream is rejected at the nozzle opening or is totally accepted and perhaps supplemented by additional quantities. In summation, *the size of gas sample is taken to be the product of nozzle area and the stack gas velocity approaching the nozzle (regardless of the velocity in the nozzle itself).*

The data previously presented on sampling errors in relation to particle size and gas velocity have been recalculated on the impaction basis with the results shown in Tables VII, VIII, and IX. They are illustrated graphically in Fig. 11, 12, and 13.

For the coarse particles (80 to 100 μ and 400 to 500 μ) remarkably small deviations are seen even where departure from isokinetic velocity is quite large.

In the case of the 5-25 μ dust grains, the sampling errors, as would be expected, are materially greater especially at low gas velocities. These facts are expected inasmuch as small particle size and small velocity are synonomous with reduced particle inertia.

Some limited measurements were made on a sample of fly ash obtained from the Cottrell precipitator of a

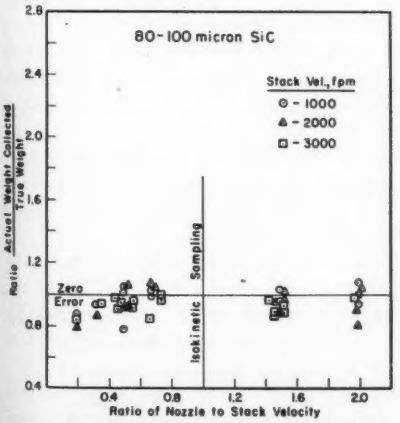

Fig. 12. Errors Due to Departures From Isokinetic Sampling (calculation based on stack velocity).

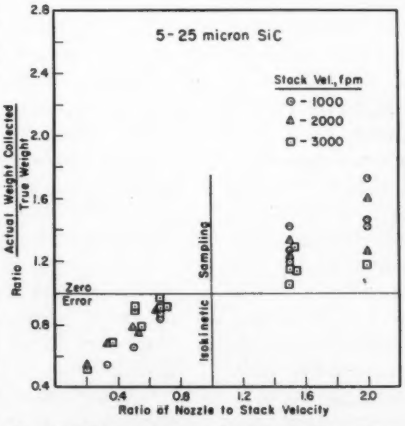

Fig. 13. Errors Due to Departures From Isokinetic Sampling (calculation based on stack velocity).

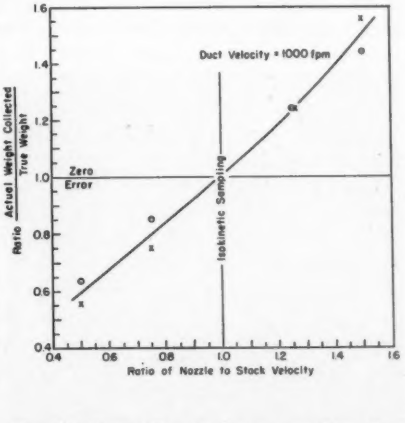
Duct Velocity = 1000 fpm
Zero Error
Isokinetic Sampling
Ratio Actual Weight Collected / True Weight
Ratio of Nozzle to Stack Velocity

Fig. 14. Errors Due to Departures From Isokinetic Sampling for Pulverized Coal Fly Ash (calculation based on duct velocity).

TABLE IX

Errors Due To Departures From Isokinetic Sampling
(for 400-500 μ SiC-calculations based on *stack* velocity)

Stack Velocity fpm.	Ratio = Actual Weight Collected / True Weight			
	Ratio of Nozzle to Stack Velocity			
	1/2	2/3	1 1/2	2
1000	(0.58)[a]	(0.64)[a]	1.04	1.18
2000	0.98	0.97	1.04	1.02
3000	0.92	1.07	0.95	.....
	0.84	0.91	0.97	.....

[a]Particle settling velocity approaches nozzle velocity

power plant burning pulverized coal. The results of this series of tests, made only at 1000 fpm., are shown in Fig. 14.

The significance of these findings can be effectively summarized in the following manner. In the sampling of coarse particles, the error due to a given departure from isokinetic conditions is greatly reduced when results are calculated on the basis of approach velocity. In sampling finer particles, there is little to choose between the two methods; the error resulting from the impaction calculation is not significantly greater or less than that from the conventional one.

The consequence is that in the measurement of any stack dust which is composed of a mixture of both coarse and fine particles the net error is materially lower when the impaction calculation is employed. In the measurement of fine dust, the error would be about the same and in the measurement of fume-like particles having little inertia, conventional calculations based on nozzle velocity would be superior.

Few industrial effluents come to mind that are typical of the last category. Even metallurgical fumes emitted from the stack of an open hearth furnace are composed of a mixture of fine fume particles with a liberal proportion of coarse dust particles. By far the commonest effluent, and this is particularly true of those from the combustion of solid fuels, are mixtures of fine and coarse particles and for this reason we regard the development herein reported to be of primary importance.

Variations in Stack Velocity

One valuable application of this discovery can result in considerable simplification of the sampling process where the sampling nozzle is moved either continuously or in steps over the cross section of a stack or flue. Conventional procedures require precise adjustment of the nozzle gas flow rate to the stack gas velocity prevailing in each position. It is clear now from the findings herein reported that considerable independence from a strict application of this rule is permissible if data are obtained by pitot tube on the gas velocities prevailing at each test position. Indeed, in some instances, if velocity distortion is not great, the nozzle gas flow rate could be adjusted to equal the average stack velocity as determined by a previous velocity traverse with only minor subsequent adjustments indicated as the test proceeds.

Acknowledgment

The work reported in this paper is a part of a research program on air pollution which has been supported by a grant from the American Iron and Steel Institute.

(Continued from page 154)

BCR Activities: 1953 and 1954

available for reducing it. Two typical charts taken from this paper, and based on work at Battelle Memorial Institute, illustrates the effect of coal fines on flue dust emission from a spreader stoker. Figure 7 relates flue dust emission with increasing percentages of minus 28 mesh material. It is interesting to note that with coal having minus 28 mesh material, there is still an appreciable emission of flue dust. With 10 per cent minus 28 mesh material, flue dust emission has increased from 2.31 to 3.0 lb./1000 lb. flue gas, or about 33⅓%. The reason for the high emission of dust with no minus 28 mesh material in the coal is due to the crushing effect of the stoker itself, plus the production of dust in the burning of the larger sizes.

Similar information is summarized in Figure 8 which is based on tests of two boilers at different burning rates. This chart relates flue dust emission against coal fines. The emission at zero per cent fines is taken as 1.0. As an example of the use of this chart, assume a boiler operating at 50 lb./sq.ft./hr. and using a coal having 20% minus 20 mesh fines. If the percentage of coal fines were reduced to 10%, the expected reduction of flue dust emission would be from 1.4 to 1.2 units, a 14% reduction.

The chart also shows that at lower burning rates the effect of fines on flue dust emission is more pronounced. The effect of the total minus ⅛ in. material is seen to be less important that the minus 20 mesh particles.

The latest subject available for presentation to groups is based on a new BCR Aid-to-Industry entitled, "Economical Operation of the Small Steam Plant". This subject should be of particular interest to members of APCA because it tries to correct some of the causes of smoke and flue dust emission at their source. The booklet gives guidance on efficient operation and maintenance of small underfeed stoker fired boiler plants. By close attention to these items, smoke and flue dust emission, which frequently are symptoms of inefficient operation, will be reduced.

Since the inception of the Combustion Conference program in January of last year, over thirty meetings have been held before a total audience of more than 2,000 engineers and coal users.

The results have been very encouraging. Engineering groups, smoke inspectors, coal companies, and other responsible bodies have expressed their appreciation by word and letter for the help the coal industry is now giving them.

The success of the Combustion Conference program has encouraged us to continue with it and expand it further. New subjects will be available for presentation based on new research results.

A New Method for Stack Dust Sampling*

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Industrial Hygiene Foundation
Pittsburgh, Pa.

In the preceding paper,[1] the fact of significance primarily related to the subject of this discussion is that in the sampling of common stack dusts appreciable departure from isokinetic sampling can often be tolerated without significant error if the size of gas sample is defined on the basis of approach velocity.

The Manifold Sampler

These findings immediately suggested the logic of multiple sampling nozzles connected in manifold arrangement for more effective coverage of a duct cross section. In the absence of the knowledge previously referred to, the objection could be raised that such an arrangement would make it impossible to adjust the velocity in each nozzle to the corresponding value prevailing in the duct. But since we have discovered that appreciable divergencies are permissible with this new system of calculation, that objection loses significance.

The first tests to demonstrate the validity of this concept in practice were carried out in the pilot plant illustrated previously[1] with the simple manifold-nozzle assembly shown in Fig. 1. The flow through the manifold was adjusted so that the velocity in each nozzle was equal to the average duct velocity. The nozzles were 3/16 in. I. D. and spaced 2 in. apart. Samples were taken in a straight vertical section nine diameters downstream from the air entrance where dust was injected. The results of several runs using three different grain sizes are set forth in Table I.

A more severe test was then planned at a location where the distribution of dust and gas velocities is extremely poor. To replace the stationary manifold whose nozzles cover but a single diameter, the mechanism illustrated in Fig. 2 was assembled. Here the manifold rotates about the center of the duct axis, sampling along an infinite number of diameters.

The selected location was in a horizontal section of the 14 in. duct, one diameter downstream from an elbow. The distortion in the distribution of dust at this location was demonstrated by disposing 26 test tubes uniformly throughout the duct cross section. The test tube assembly is shown in Fig. 3. A quantity of dust, 80 to 100 μ in size, was fed into the system. The relative amount impacted into each tube is shown in Fig. 4 (a) and 4 (b).

The results of the first series of sampling efficiency tests employing the rotating manifold are shown in Table II.

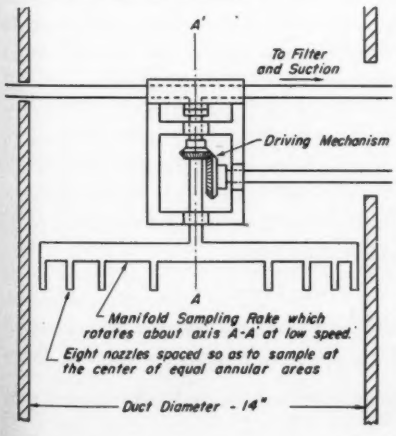
The reason for the low sampling efficiency became apparent when it was discovered that an extremely high proportion of the total dust was concentrated in a layer about 0.5 in. thick adjacent to the wall in the lower left quadrant, which was not reached by the outermost nozzle in the rotating rake.

To overcome this condition a semi-circular baffle or dam, 1 in. in width was inserted adjacent to the wall approximately 6 in. upstream from the sampling location. Dust particles approaching this weir were diverted over it and thus re-suspended in the main stream of air. The position of this baffle is shown by the dotted lines in Fig. 4 (b).

The dust distribution was again determined as described previously except with the baffle in place. Fig. 4(b) in comparison with Fig. 4(a) shows how the bulk of material previously hugging the wall has been diverted somewhat towards the central portion of the cross section, although the overall distribution is extremely distorted.

*Presented at the Semi-Annual Meeting of the American Society of Mechanical Engineers, June 22, 1954, Pittsburgh, Pa.

(1)Hemeon, W. C. L. and Haines, G. F., Jr., "The Magnitude of Errors in Stack Dust Sampling."


A'
To Filter and Suction
Driving Mechanism
A
Manifold Sampling Rake which rotates about axis A-A' at low speed.
Eight nozzles spaced so as to sample at the center of equal annular areas
Duct Diameter - 14"

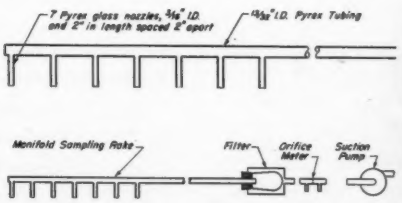

7 Pyrex glass nozzles, 3/16" I.D. and 2" in length spaced 2" apart
(3/32" I.D. Pyrex Tubing
Manifold Sampling Rake
Filter
Orifice Meter
Suction Pump

Fig. 1. Original Sampling Rake and Sampling Assembly.

Fig. 2. Rotary Sampling Rake.

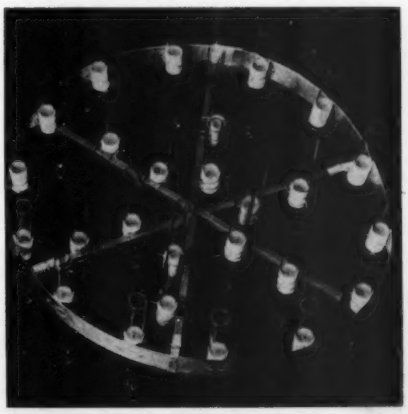


Fig. 3. Assembly of Impaction Tubes Used to Explore Distribution of Dust in Circular Duct.

TABLE I

Sampling With A Fixed Manifold Sampling Rake
(7 Nozzles Spaced 2 in. Apart Across A 14 in. Duct)

Silicon Carbide Size in μ	Sampling Efficiency %
420 - 500	87
420 - 500	76
80 - 100	109
80 - 100	99
80 - 100	100
5 - 25	93
5 - 25	92

TABLE II

Sampling Efficiency of the Rotating Manifold Rake Located One Diameter Downstream From The Right Angle Bend (Average Duct and Nozzle Velocity, 2000 fpm.)

Silicon Carbide Particle Size μ	Sampling Efficiency %
80 - 100	72
80 - 100	75
80 - 100	77
80 - 100	72

TABLE III

Sampling Efficiency of the Rotating Manifold Rake Located One Diameter Downstream from a Right Angle Bend With a Semi-Circular Baffle 1 In. in Width Adjacent to the Wall and Approximately 6 In. Upstream from the Rotating Rake
(Average Duct and Nozzle Velocity, 2000 fpm.)

Silicon Carbide Particle Size μ	Sampling Efficiency %
420 - 500	96
80 - 100	93
80 - 100	100
80 - 100	86
80 - 100	91
5 - 25	95

TABLE IV

Sampling Efficiency of the Rotating Manifold Rake Located One Diameter Downstream from a Right Angle Bend With a Complete Circular Baffle 1 In. in Width Adjacent to the Wall and Approximately 6 In. Upstream from the Rake
(Average Duct and Nozzle Velocity, 2000 fpm.)

Silicon Carbide Particle Size μ	Sampling Efficiency %
80 - 100	92
80 - 100	96
80 - 100	95
80 - 100	93

Six tests were made with the rotating rake 6 in. downstream from the baffle. The results are summarized in Table III.

These results showed gratifying confirmation of the validity of the new sampling concept.

Some additional runs were made with a complete circular baffle. The results are about the same as previously found with a partial baffle, as shown in Table IV.

Plant Scale Tests

Steps next were taken to demonstrate the method on a large scale at a boiler plant located near our laboratories. The test site is a rectangular breeching, 6 ft. wide by 12 ft. deep. The sampling location is an extremely poor one as shown in Fig. 8, with a bend and a sub-breeching occurring less than half a diameter upstream.

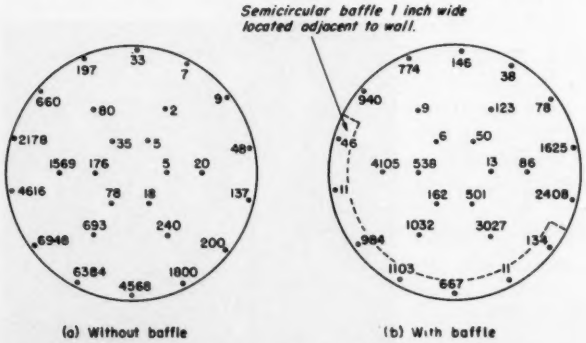


Fig. 4. Distribution of Dust in a 14-Inch Horizontal Duct.

One diameter downstream from a 90° elbow. Figures shown are weights in milligrams impacted into test tubes. Feed = 700 grams of 80 - 100 Micron Silicon Carbide Grains.

The apparatus illustrated in Fig. 6 was designed for use as shown in Fig. 7.

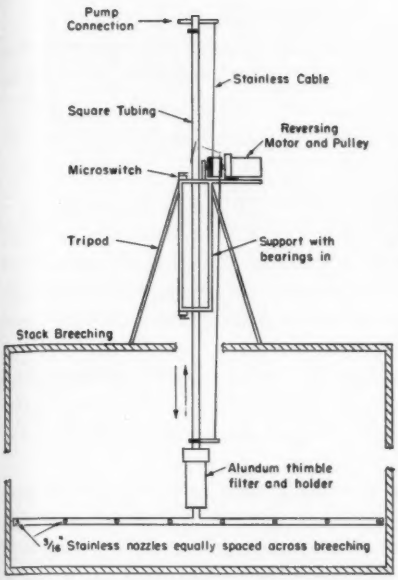
The rake, arranged for vertical rectilinear motion, consists of an aluminum sampling tube ½ in. inside diameter with eight 3/16 in. nozzles equally spaced across the length of the tube. The relatively large diameter of the header in relation to the nozzles, results in only small differences in the flow through the outermost nozzle compared with the ones near the center. The central nozzle handles 12% more gas than the average and the nozzle most remote 12% less than the average.[2] The two arms of the header are each 30 in. long connected by means of a T to the alundum thimble housing. The advantage of this arrangement is in the fact that there is a minimum length of tubing (two 30 in. lengths in this instance) needing to be cleaned out at the end of a test.

Square connecting tubing leads from the thimble holder to the duct exterior where it passes through a support on a tripod. A small reversible motor operating small cables provides the drive to move the rake up and down throughout the duct cross section, and microswitches actuate the reversing mechanism of the motor.

Dust Weir

In considering the sampling location, we had in mind the experience with the 14-in.-duct pilot plant tests where-

(2) This 12 % value was later reduced to 5% by increasing the header diameter from ½ in. to ⅝ in.



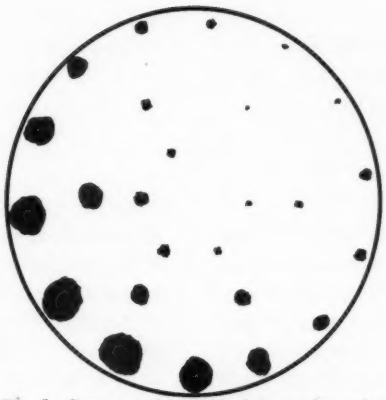


Fig. 5. Contents of individual impaction tubes from test described in Fig. 4(a) dumped on a plate. Depicts extreme degree of maldistribution.

Fig. 6. Manifold Sampling Rake for Rectangular Ducts.

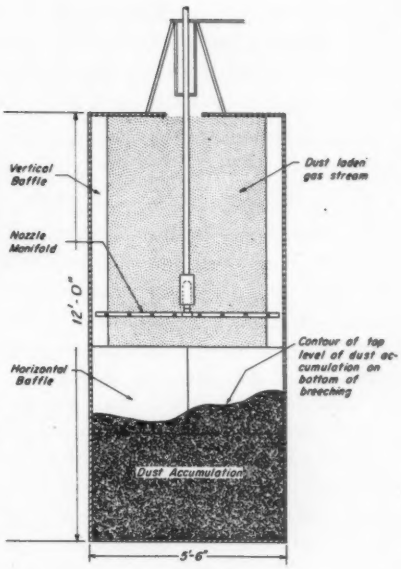


Fig. 7. Cross-Sectional View of Boiler Breeching at Test Location.

in interference with proper sampling was encountered due to high concentrations of dust moving in a thin layer adjacent to the duct wall. The identical problem was seen in the horizontal breeching since it was apparent that large quantities of dust must creep along the bottom due to their weight and the low gas velocity. In fact, at the time of these tests there was a 3 or 4 ft. accumulation of dust on the bottom. Accordingly, a baffle or weir was fabricated of sheet metal, in two sections, each with a long handle. These were forced downward into the accumulated material on the bottom of the flue, leaving a portion projecting upward a distance of from 10 to 12 in. (Fig. 7).[3] This incidentally reduced the cross sectional area and increased gas velocities from 1000 fpm. to 1400 fpm. (300°-350°F.)

Demonstration of Validity of Results

We sought a method that would make it practical to demonstrate the efficiency of the new sampling apparatus by independent objective means and it was concluded that the test method employed for this purpose at the pilot plant could be applied here also. Accordingly, a quantity of pulverized coal fly ash was obtained from a power plant for the tests described in the following: 50 lb. of fly ash were injected into the breeching approximately 30 ft. upstream of the sampling location by means of a compressed air ejector at a rate of 2 to 5 lb./min. The manifold sampler was operated for a 30 min. period prior to each test run to determine the background concentration of flue dust and that was subtracted from the concentration found from the test made for the determination of sampler efficiency.

It should be noted at this point that the results obtained in the pilot plant tests (Tables III and IV) involved coarse grains of dust, 80 to 100 μ in diameter. The fly ash employed in these full scale tests is much finer and greater inherent errors are to be expected for a particular departure from isokinetic sampling, even though the gas sample is defined on the basis of approach velocity. The results of the first six tests appear in Table V.

In seeking to improve the results, consideration was given to the possibility that the ash was ineffectively dispersed by the compressed air ejector, and some minor changes were made in the dispersing mechanism. Attention was then turned to the relative velocities in the sampling nozzles and at various points in the duct cross section. In a computation of the ratios of duct velocity to sampling velocity of the several nozzles, the data given in Table VI were obtained.

When the data of Table VI and Fig. 14 of the preceding paper[1] are combined, we obtained the estimated sampling errors for different portions of the duct cross section as set forth in Table VII.

TABLE V

Efficiency of Traversing Manifold Sampler in Low Velocity Horizontal Breeching on Sampling Air Injected Fly Ash

Fly Ash Dispersion Rate lb./hr.	Collection Efficiency %	Baffles
240	85	Vertical traverse one foot downstream from a baffle located at bottom of breeching.
282	80	
136	73	
273	70	Vertical traverse one foot downstream from a baffle located at bottom of breeching. Also side baffles 6 in. wide extending from bottom baffle to top of breeching.
87	59	
108	81	

(3) Vertical baffles shown in Fig. 7 were tried out and subsequently eliminated.

1. Same footnote (1) page 165.

TABLE VI

Ratio of Duct Velocity to Average Sampling Velocity of the Several Nozzles
(Figures are for a 16 point traverse)

.67	.73	.71	.73
.89	1.07	.90	1.28
1.11	1.14	1.18	1.24
.86	1.22	1.32	1.32

In order further to illuminate the pertinent factors, the distribution of dust flow was explored by mounting at 24 points throughout the cross section a number of impaction tubes facing upstream. From the weights collected in the several tubes, the dust distribution was inferred to be that depicted in Fig. 9. This figure shows the dust to be stratified from top to bottom and with a high concentration in the lower right quadrant.

These various data do not permit conclusions based on unequivocal proof concerning the exact cause of the errors evident in the six runs described in Table V. It is our opinion, however, based on the estimated errors set forth in Table VII, taken in conjunction with the indicated distribution of dust in Fig. 9, that it is due to the fact that nozzle velocities were too low for the lower right area of the duct cross section where a major proportion of the dust apparently flowed.

It was not practical for us to continue a study of these particular questions nor was it necessary to a demonstration of this method. We simply acted on the magnitude of demonstrated error, raised the air flow through the nozzles about 20% higher than in the previous runs and obtained the gratifying results presented in Table VIII.

TABLE VII

Approximate Sampling Errors for the Departures from Isokinetic Sampling Shown in Table VI

+49	+36	+40	+36
+11	— 6	+ 9	—18
— 8	—10	—12	—15
+14	—15	—20	—20

Overall sampling error = +4%

Rotary Manifold Sampler

Supplementing the apparatus previously described for use in rectangular ducts is the rotary sampler illustrated in Fig. 10. This model is made up of the following components:

1. A nozzle manifold with adjacent filter holder which rotates throughout the cross section about the axis of the stack. The nozzles are located along the manifold at the center of equal annular areas;

2. One end of a connecting shaft (which is hollow and serves doubly as the filtered gas conduit) attaches to the side of the filter holder while the other end is supported in a bearing housing which allows it to rotate;

TABLE VIII

Final Tests on the Sampling Efficiency of Traversing Manifold Sampler for Injected Fly Ash

Fly Ash Dispersion Rate lb./hr.	Collection Efficiency %	Baffles
138	95	Vertical traverse with a baffle located across the bottom of the breeching and extending 1 ft. above the dust accumulation.
166	96	

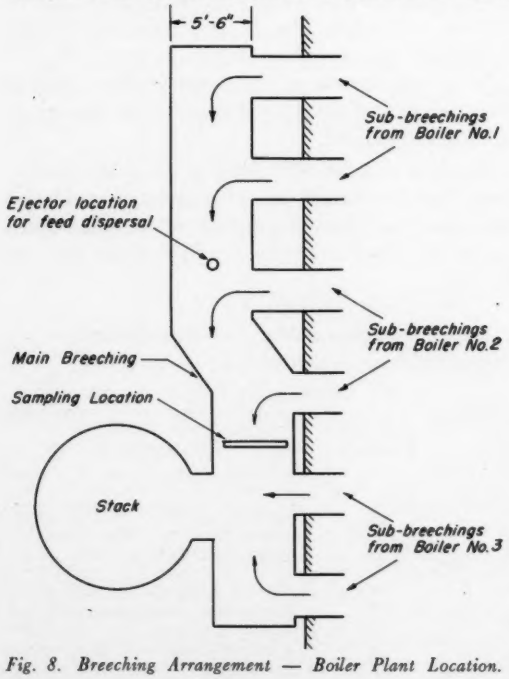


Fig. 8. Breeching Arrangement — Boiler Plant Location.

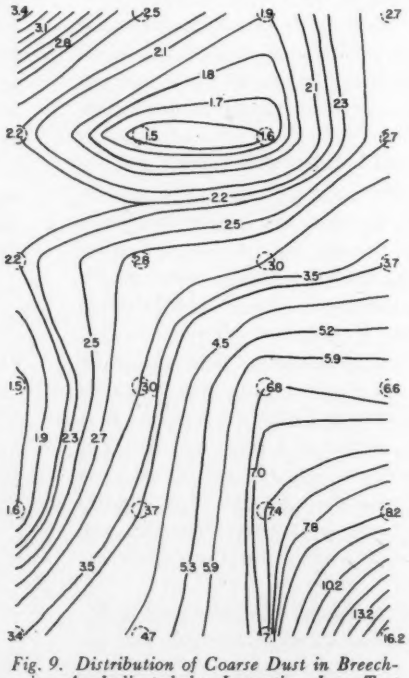


Fig. 9. Distribution of Coarse Dust in Breeching As Indicated by Impaction Into Test Tubes.

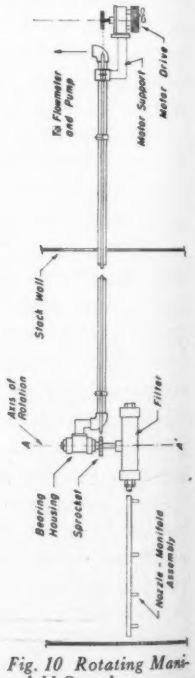


Fig. 10 Rotating Manifold Sampler.

3. Connecting sampling tubing extends from the bearing housing to the stack exterior where the flowmeter and pump are located; and

4. An optional chain and sprocket drive automatically driven by a 15 rpm. motor.

Summary

In summarizing, attention is drawn to the fact that the boiler plant duct location in which the final tests were made, represented in every respect the most unfavorable conditions that might ever be encountered. The flow is in a horizontal duct; the gas velocity was very low; and nothing resembling a straight run preceding the test location existed.

The essential base upon which rest the conceptions and methods that have been outlined are as follows:

1. Use of the approach velocity as a definition of size of gas sample minimizes errors for which the largest particles in a mixture are responsible, and the larger the particles, the more nearly the error approaches zero. The practical significance of this is in the fact that the large majority of stack dusts include coarse particles with the fine and one of the most critical influences on test results is in the representative sampling of the coarse particles. They are the ones tending most to stratification.

By adjusting the average nozzle velocity in the manifold assembly to the average velocity prevailing in the stream being tested one may expect during the traverse that errors in sampling the finer dust would be positive in some locations and negative in others and that because of the infinite number of sampling locations individual errors will tend to become nullified. However, a net error can be expected where there is extreme distortion in the distribution of the fine dust.

2. The use of a baffle or dam on the floor or against any wall where undue concentration of dust may occur is an invaluable device to insure complete sampling of the total dust flowing. It is also useful in raising very low velocities to more satisfactory levels.

3. In particular cases where proof as to the accuracy of the sampling system is important, one may specify the supplementary procedure described, consisting in the injection of known weights of dust upstream from the sampling location.

Acknowledgment

The work reported in this paper is a part of a research program on air pollution which has been supported by a grant from the American Iron and Steel Institute.

(Continued from page 124)

Atlantic Control Program

The Medical Department
The Research and Development Department
The Waste Control Group

In order to provide flexibility and make possible quick, on-the-spot investigations the Waste Control group has been provided with a mobile laboratory in the form of a well equipped truck. This laboratory on wheels contains equipment for collecting samples and carrying out all forms of analyses necessary to our investigations.

This committee meets once each month or more frequently if necessary. It plans investigations, keeps records of findings and analyzes these findings to determine what action should be taken to eliminate pollution from the sources found.

The plant committee also participates in the activities of various groups similarly engaged within the Philadelphia area. This participation is of value for several reasons. In the first place, it permits ready comparison of analytical procedures, thereby promoting accuracy. It permits similar comparisons of methods of pollution abatement, thereby extending the technical "know-how" being directed toward abatement. Finally, there is a comparison of the analytical results obtained by these other groups for the determination of how the various plants may be affecting one another.

The mobile laboratory has a role in this activity. It can take positions at various points, and working with laboratories operated by other companies, a composite result of atmospheric findings under various conditions of wind and weather over the entire area is made available.

There is one other feature of our Philadelphia Refinery program and that is the "smoke detective" or "watchman." This individual is charged with the duty of watching for any emission of smoke over the plant. Upon seeing smoke, he immediately determines the unit from which it is coming and reports the emission to the head of the department operating that unit. The Philadelphia ordinance permits a minor discharge of smoke for a few minutes (Ringelmann Chart No. 3 for two (2) minutes in any fifteen (15) minutes, but not more than three (3) times in any twenty-four (24) hours). If the smoke emission is not cleared up within the allowable time, the smoke watcher either again calls the department involved, or he may call the plant management who will act promptly to have the matter corrected. With this arrangement, a smoke consciousness has been developed which is producing a relatively smoke free plant.

The organization described above has been in operation for over two years and is bringing about very good

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results. For one thing, it has shown that the refinery it not as bad as many of us thought since the SO_2 - SO_3 figures obtained as results at stations about two miles from the refinery limits are not too serious. Further, it has pointed out the major sources of air pollution; and complaints within and without the plant boundaries have been greatly reduced. In fact, our smoke situation has been referred to as excellent by City authorities.

(Continued from page 140)

New Uses of Electrical Precipitation

Cement Industry

For many years, the only application for the Cottrell precipitator in the cement industry was the removal of dust from kiln and dryer discharge gases. Recently, however, the precipitator has been used to recover dust from Bradley Mills and auxiliary conveyor equipment in the finish mill buildings of a cement plant (Fig. 8). This recovery job varies somewhat from the kiln precipitator application in that the inlet temperature at the precipitator is in the range of 90° to 100°F. and involves the cleaning of air, whereas on kiln precipitators flue gases are cleaned at temperatures in the range of 400° to 700°F. Dust concentrations handled by the Bradley Mill installation average 30 to 70 gr./ft.^{3} This concentration is 3 to 7 times greater than that found in normal kiln flue gases. In this connection, we would point out that the material recovered in the Bradley Mill precipitator is salvaged and returned to the process. As the temperature and volume of the ventilating air from Bradley Mills are rather low, it is significant that the precipitator serving these mills is substantially smaller than an installation handling kiln gases. Therefore, the problem of space limitation is not nearly so acute on this application as that on the kiln gas precipitators. The horizontal flow, plate type precipitator is employed for our installations; and, as mentioned above, the high dust loading necessitates a precipitator designed for extremely high recovery.

Conclusion

In view of the above described installations, one can readily see that industries have been very cooperative in attempting to reduce and eliminate serious air pollution problems. The managements of manufacturing concerns have spent a great deal of time and money in attempts to ascertain the types of equipment best fitted for their particular problems. Without their aid, cooperation, and foresight, it is doubtful that the air pollution abatement program could be the success it is today.

DISCUSSION OF PAPER BY S. E. SPECHT AND R. W. SICKLES ENTITLED "NEW USES OF ELECTRICAL PRECIPITATION FOR CONTROL OF ATMOSPHERIC POLLUTION"

The authors have prepared a valuable paper discussing new uses for electrical precipitation equipment.

The Philadelphia Electric Company has installed modern and efficient fly ash collectors initially with all its pulverized-fuel-fired, steam generating units. The first two electrical precipitators were installed at Richmond Station in 1935. In rapid succession collectors were installed until in 1949 combination units were installed at Barbadoes Station. This installation comprised a mechanical collector followed by an electrical precipitator. Subsequent installations, including Cromby No. 1 and No. 2 scheduled for operation in 1954 and 1955, include high efficiency combination units.

Experience with modern pulverized-fuel-fired boilers of the dry ash type indicates that fly ash particle size in the gases going to the collectors approaches 40% less than 10 μ size. This imposes a very heavy duty to the collector inasmuch as up to 80% of the coal ash is in the form of fly ash.

Since the larger particle sizes are readily collected in the first mechanical collector and the smaller particle sizes are precipitated in the secondary or electrical precipitator, combination units lead to high overall efficiency.

In addition, mechanical collector efficiency increases with load, electrical precipitator efficiency decreases with load. Their combination results in high overall sustained efficiency.

The Cromby boilers with a rating of 1,050,000 and 1,450,000 lb./hr. and fired with pulverized coal will place a severe demand on the fly ash collecting equipment. An overall efficiency above 98½% collection is anticipated, based on 85% mechanical collection and 90% electrical collection.

We want cleaner air and we want to keep it clean. High collection efficiency equipment of the type presently under discussion is our answer.

D. F. Schick, Jr.
Philadelphia Electric Company

(Continued from page 142)

Industrial Odor Control

each plant will have an effect on the completeness of odor abatement and it will be necessary to run a field test to determine the best possible location. Regular plant personnel usually are not sufficiently experienced in odor abatement work to be entrusted with the solution of this problem. In most instances they have worked for the plant for some time, have become accustomed to the odor and cannot consider the problem objectively. Physical defects involving the sense of smell render it difficult for an individual to trace odors. Much time and effort can be saved if people experienced in this work are obtained. In many plants we have found that better control of the odor is obtained by the installation of extra guns and the use of more dilute materials. Proper abatement is accomplished when better than 90% coverage is obtained even under the most severe conditions of adverse weather.

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Masking agents and odor counteractants are injecting themselves into everyday life. One of the first deodorants was based on chlorophyll. Now, however, chlorophyll is relegated to a minor role and other counteractants have been found which will control industrial atmospheres. For years masking agents have been used to cover the odor of sulfur compounds in kerosene solvents for insecticides. In some instances, masking agents are used to deodorize straight-run gasolines which contain sulfurous substances. Recently deodorants have been found to neutralize the odor imparted rugs and clothing by storage with moth balls. Every year, millions of dollars of smoke damaged merchandise are saved by the use of other counteractants. Odors from sewage systems, rendering plants, and slaughter houses can now be destroyed by various odor counteractants. The use of completely recycled air conditioning units has made it necessary to destroy the stale odors produced by human occupancy and tobacco products. This is done by odor counteractants and in some minor instances by masking agents. One of the most unusual instances is the use of odor counteractants to cover animal and excreta odors at dog shows. We are developing considerable dependence upon masking agents and odor counteractants.

DISCUSSION OF PAPER BY W. A. QUEBEDEAUX, JR., ENTITLED "NEW APPLICATIONS FOR INDUSTRIAL ODOR CONTROL"

I wish to commend Dr. Quebedeaux for an excellent presentation on industrial odor control.

Odor reactants have a definite place in odor control. They are quite useful under the following conditions:

The malodor has been identified and it consists largely of one functional group.
A low-cost reactant is available for the identified malodor.
The reaction conditions are amendable to control and provide sufficient time for the reaction to go to completion.
Although the reactant is very reactive chemically, it is non-toxic to humans and is non-irritating to the mucosae.

We have used odor reactants for odor control of certain petroleum products. Generally, however, we have found masking agents more practical than odor reactants.

Dr. Quebedeaux stated that masking agents require treatment of an entire process. However, we have several installations where the masking agent is used to treat the effluent only—not the entire process. This is being done to the satisfaction of the company, the community, and the air pollution authorities. Nor is any additional quantity required for spills.

Masking agents are affected by rain or high humidity in the same way as the malodors.

Our masking agents can be diluted with water for economical feeding to atomizing equipment. With proper selection of masking agents, zero odor can be approached in the same manner as with odor reactants.

We would like it to be known that there are masking agents available and in actual commercial use which do not have the disadvantage of those tested by Dr. Quebedeaux.

R. Pantaleoni
van Ameringen-Haebler, Inc.
New York, N. Y.

(Continued from page 150)

Automatic Sampler Measurement Program Discussion

turn effects the pollution level. One serious fault with long sampling periods is that the density of the spot could have built up during the first hour, thus causing the evaluation of the entire period to be erroneous. For these reasons we have chosen a sampling period of 1 hr. I might point out here that the length of the sampling period will have to be governed to some extent by the pump rate of the sampler. Gruber has pointed out that he selected a sampling period of 6 hr. to obtain results from a minimum number of samples. We do not doubt that he obtained very good results in evaluating the pollution level from such 6 hr. samples, but we do feel that he would have obtained even greater results or information with a shorter sampling period.

Objective 4. Certain rolls and rolls of spots are not only difficult to store but equally hard to evaluate quickly. For that reason they must be translated into a recordable unit. Once the unit is obtained, a log sheet can be established and appraisals of past spots obtained at a glance. We have chosen the Coh unit perfected by Hemeon for two reasons: first, the evaluation is fairly simple and second, the evaluation assembly (light transmission) is easy to use and inexpensive.

Objective 5. Correlation of the spot with industrial and/or domestic activity is certainly desired. Long sampling periods make this correlation practically impossible. In averaging our hourly spots for a 3 month period (January, February, March) we found that maximum densities occurred between 6:30 and 8:30 a.m., and a secondary maximum occurring approximately from 6:00 to 9:00 p.m. These maximums can be safely assumed to be caused by:

1. Increased industrial activity coupled with increased firing for heating purposes.

2. Increased turbulence due to solar heating.

3. Decreased turbulence in the evening hours before the rate of industrial pollution has been reduced.

Thus, from this example you can readily appreciate how better correlation can be obtained from shorter sampling periods.

Objective 6. In many cases we are too prone to state improvement of an area without definite or substantiating evidence. Spot sampling over a long period of time will provide information as to whether conditions are improving or not, remembering that spot sampling evaluates only one phase of air pollution.

When we first began the spot sampling program, we had planned to use the information obtained as a guide to establish other sampling programs similar to that outlined in point 6 of Gruber and Alpaugh's summary. However, our opinion concerning this has changed somewhat. We have compared SO_2 concentrations obtained from an autometer operating in a general area of the spot sampler and have found that correlation to-date of high SO_2 and dense spots, does not exist. In fact, in many instances the complete opposite is experienced.

The instrument has to be placed in its proper perspective, i.e., its results cannot be interpreted as a true measure of the overall pollution level but rather only one phase of it. We have found that in many cases where numerous complaints have been made on odors, irritations, etc., the spot densities have been extremely low. On the other hand, we have experienced days of dense spots when no complaints have been received. We have found that shallow inversions do not necessarily mean dense spots. These points are not made to discourage the use of the spot sampler but rather to indicate what you might expect from this type of program. Spot sampling is a very important phase of any continuous sampling program and will add much to the knowledge of local air pollution levels.

1. Hemeon, W. C. L., Haines, George F., and Ide, Harold M., "Determination of Haze and Smoke Concentrations by Filter Paper Samplers". **Air Repair**, 3, 22-28, August 1953.
2. Shaw and Owens, "The Smoke Problem of Great Cities", London, Constable and Company, Ltd., 1925.
3. Davidson, W. F., "A Study of Atmospheric Pollution". **Monthly Weather Review**, 70, 225-34 (1942).

John C. Marks
Air Pollution Control District
Jefferson County, Ky.

(Concluded on next page)

I have had the conviction for a long time that filter paper samplers, operating on a 24-hr. schedule, were a valuable piece of equipment in air pollution work, giving as they do a continuous and complete record of exposure. The instruments are ideal for measuring the "dirtiness" of the atmosphere, as the present authors have shown, though some people might prefer to take six or eight samples per day instead of only four.

It is entirely reasonable to expect that pollution in a city would be greatest when wind velocity is low and inversions are present. Most of the smoke in Cincinnati doubtless comes from domestic heaters or low stacks. Being emitted close to the ground it stays there, particularly with inversions and with wind velocities of 4 to 6 mph. or less. With lapse or higher velocities it tends to rise or be blown away. It is of interest to note the troughs in the pollution record in the afternoon samples (period No. 3) especially in Fig. 3 and 4. This is the time of strongest lapse, usually attended by an increased wind velocity. On November 13 there was a sharp decrease in pollution without an appreciable increase in wind velocity, due probably to lapse.

The pattern of smoke-meteorological relations developed in this paper corresponds closely with our observations in Salt Lake City as described in the A.E.C. Handbook on Aerosols, pp. 28-33, 1950.

M. D. Thomas
American Smelting and Refining Co.
Salt Lake City, Utah.

Author's Reply

Dr. Katz commented that the 6 hr. sampling period might be too long in areas where the pollution load is heavy. To this view we subscribe. However, in Cincinnati, we have reduced the sampling rate at the Bureau of Smoke Inspection, or highest pollution level station to about one-half of that of the instruments located in the suburbs. This can be done because we have a separate vacuum pump on the BSI station sampler. The new samplers draw about 16,500 linear ft. of air in 6 hr. whereas the flow rate through clean filter paper of the sampler at the BSI station has been set at 8600 linear ft. in 6 hr.

In the field of air pollution measurement, it is quite rare to find the degree of agreement or parallelism of data that has been found by the several independent users of the automatic filter paper sampler. This would indicate that the filter paper sampler will become more and more useful in the study of urban air pollution.

DISCUSSION OF PAPER BY ROSS N. KUSIAN ENTITLED "PLANNING A STATE-WIDE AIR POLLUTION ADVISORY SERVICE"

The different approach used by each community to attack the air pollution problem is of interest to everyone. The local nature of the problem must recognize that a variety of approaches may be necessary. The author presents a plan for an advisory service operating under state control. This method of assistance to local communities and to industry may prove to be of great value.

This approach recognizes the need for preventive air pollution control measures. It should not be confused with the problem of controlling atmospheric pollution where the effects of polluted air are already a serious community problem.

We, in the Association, must be the first to recognize and study the progress that is made by the different programs either to control existing pollution or to prevent the community-wide ill effects of polluted air. Marked differences exist in the programs being carried on to control pollution in Allegheny County, Los Angeles, San Francisco and other cities. Each of the existing approaches may be successful in control measures. Similarly, different approaches will develop preventive air pollution measures, such as zoning, standardization of air pollution control practices and counseling services. The development in the State of Washington will furnish helpful information to all and their success will add much to the information which is needed by other communities. It is essential that programs now being carried out in several directions not be made the targets of criticism by other air pollution officials because one program directs a course of action different from that of another community. Rather, each should accept a new approach to enhance our knowledge in the effort of avoiding the nuisance of air pollution.

Gordon P. Larson
Air Pollution Control District
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Mr. Kusian raises the very interesting problem of the community whose dominant or only industry is a source of air pollution and notes that few objections are publicly expressed in such places. This is the result of several factors. There is the fear on the part of the hourly wage earner and his family, accustomed to thinking in terms of small sums, that the obviously large expenditure to correct the situation would force his employer to move the mill or to go out of business. How unfounded this fear really is, we all know—but he doesn't.

A second factor in such situations is that mill management and local mill owners (where they exist) are usually also the gentry of the community and, as such, are the officers of the civic, social and political groups which form mass opinion. Where this dominance exists, it is unpopular to express adverse opinions about such matters as air pollution from the mill.

Thirdly, some mill town governments are controlled by the mill management to the extent that the mill manager has the power to name, or at least veto, the electoral slate of the dominant political party in the community.

Fourth, a critical factor is the attitude of the mill labor union. In too many instances, unions are willing to bargain a list of grievances such as dust, gas, fume and odor in workplaces and in the air their families breathe against more apparent economic goals, such as wages, hours, vacation, pensions, and insurance. When management yields on the latter front, union pressure on the former is held over till the next contract negotiation period. There is a very strong correlation between dust, gas and fume problems in single industry areas brought to the attention of enforcement officials and unsuccessful termination of union contract negotiation.

Then there is the matter of the local press. This is a highly personal matter, hinging on the makeup and motivation of the editor and publisher (they are usually one). An aggressive editor can break such a situation—or can himself be broken in the process.

Lastly, there is the question of where local individuals, groups or government can go for outside help. If the State provides no assistance, they are frequently stymied. Where an organization exists such as Mr. Kusian describes for the State of Washington, requests for guidance will not be pigeon-holed, nor will such matters end up in the hands of lawyers to whom a quick injunction may mean a "quick buck". In the State of Washington the prospect is that mill management, local government and other parties at interest will be gotten around a conference table and supplied with expert advice and guidance, and that a solution satisfactory to all will be achieved.

Arthur C. Stern
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I have read with considerable interest Mr. Kusian's paper on "Planning a State-Wide Air Pollution Service". He has pointed out the industrial growth of the Northwest and I must admit that this fact puts him in the rather enviable position of being on the spot during the industrial expansion and enabling him to press for air pollution control at a time when industry is most receptive and able to install control equipment. We in the East know the problem facing industry when it wishes to install controls in already existing plants, and appreciate the difficulties sometimes encountered. His analysis of complaints is typical and, with a few exceptions, the complaints are like those encountered by everyone in this work. I note, however, he did not mention the chronic complainers which some of us have. No doubt he, being a kindly gentleman, did not bother to mention this.

The laws existing for the control of air pollution in the State of Washington are much the same as those in Pennsylvania and, I suspect, in many other states. The differences in the two states and, I have reason to believe, in many others, lies in the interpretation of the laws, generally the result of an executive order by the Governor.

Mr. Kusian has made several statements I think worthy of stressing:

1. Industry, in general, is doing all it can to prevent and control air pollution.
2. Legal means of controlling excessive air pollution usually exist but the enforcement is not adequate to bring the recalcitrant industries in line.
3. There is need for technical assistance and encouragement at the state level.

I further think that Mr. Kusian has presented his case soundly and in no way jeopardizes the jurisdiction of local authorities. I think that his plan to obtain support from the state is admirable and will enable him to render a more efficient service than could be done otherwise. It is my belief that air pollution at the state level should be state supported.

There is, however, one unanswered question in my mind, "How can the state, under existing laws, act to obtain relief from air pollution for the citizen when this pollution is considered to be a nuisance and local officials are either nonexistent or unwilling to pass or to enforce an existing nuisance ordinance."

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